City of New Haven Long Term CSO Control Plan

The City of New Haven

New Haven Water Pollution Control Authority

Technical Memorandum #6
Hydraulic Characterization Report

CH2MHILL

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March 9, 2000

135807.BA.04

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Subject: New Haven LTCP Project Task 4—Hydraulic Characterization

Dear Sirs:

Enclosed for your review and comment is a draft of Technical Memorandum 6. This memorandum documents the hydraulic characterization for Task 4 of the Long-Term Control Project. It includes the results of model simulations for four design storms and an average year and describes water quality issues and pollutant loads affecting the receiving waters.

Sincerely,

CH2M HILL

Peter von Zweck
Project Manager

cc: Cliff Bowers/CH2M HILL
Bill Hogan/CT DEP

CITY OF NEW HAVEN LONG-TERM CSO CONTROL PLAN

TECHNICAL MEMORANDUM #6

Hydraulic Characterization Report

Prepared for

The City of New Haven
The New Haven Water Pollution Control Authority

Prepared by

CH2MHILL

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February 2000

135807.BA.04

Acknowledgments

CH2M HILL gratefully acknowledges S. Anisfeld, T. Trexler, M. Steinhoff, K. Bennett, G. Benoit, and P. Barten from the Yale University School of Forestry and Environmental Sciences for sharing their water quality data.

Executive Summary

In 1997, the City of New Haven began work on a Long-Term Combined Sewer Overflow Control Plan (LTCP). Since then, through a series of workshops, the project's Stakeholders have identified meeting water quality standards and protecting critical areas as the highest priority goals of the program. This report provides a characterization of water quality issues in the Quinnipiac River, Mill River, West River, and New Haven Harbor. These issues include the current conditions in the water bodies and the factors—such as sources of pollution—that have contributed to the present conditions. Each of these water bodies contains a number of "sensitive areas" and has existing or proposed uses that are not fully supported by its existing water quality. The data, results, and observations contained in this report will be used as the foundation for the evaluation of Combined Sewer Overflow (CSO) control concepts.

Sensitive Areas and Uses

The rivers in New Haven contain a number of areas used for swimming, fishing, canoeing, boat launches, marinas, and other recreational uses. Parks bordering the rivers are used for a broad range of other recreational uses including walking, hiking, jogging, and athletics. All of these activities can be considered sensitive to water quality.

New Haven Harbor is bordered by four recreational areas, four marinas, and New Haven's only designated bathing beach. In addition to supporting these recreational uses, New Haven Harbor contains several shellfish beds that are used for harvesting or (because of water quality issues) seeding and relocation. These activities also are highly dependent on water quality. A map showing the location of water bodies, sensitive areas, and recreational facilities is provided in Figure ES-1.

Water Quality Standards and Criteria

The Connecticut Department of Environmental Protection (CT DEP) has established water quality standards and criteria for surface waters. The classification system addresses current conditions and also sets goals for restoration of water quality. Grade AA is the highest classification and represents water bodies which can be used for drinking water supply. Grades A and B (or SA and SB in salt environments) generally represent water bodies which support high-end recreational uses, including fishing and swimming. All of New Haven's water bodies have a restoration goal that will support these uses (see Figure ES-2). Waters where these goals are not consistently achieved or water bodies that are

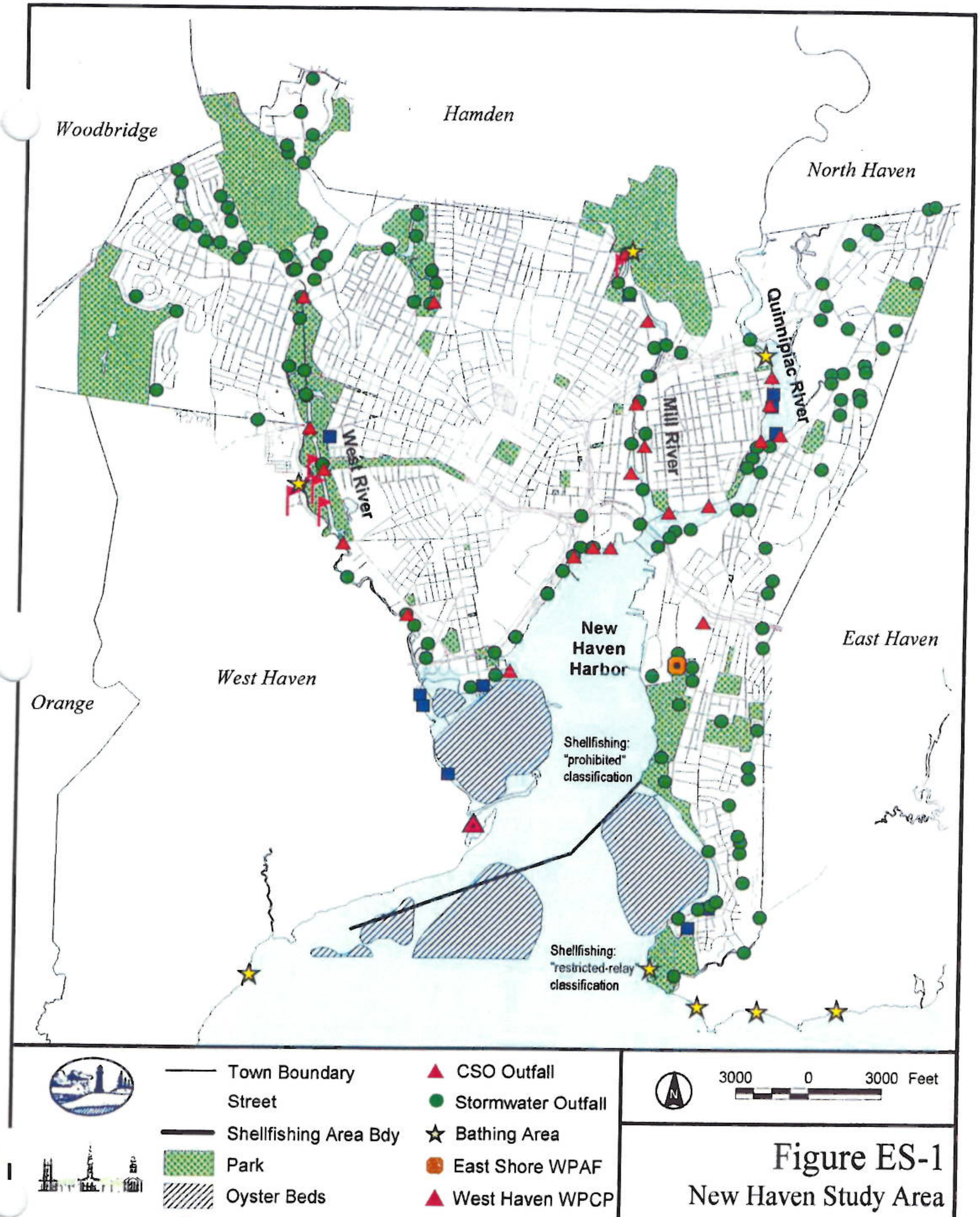


Figure ES-1
New Haven Study Area

New Haven Long Term CSO Control Plan

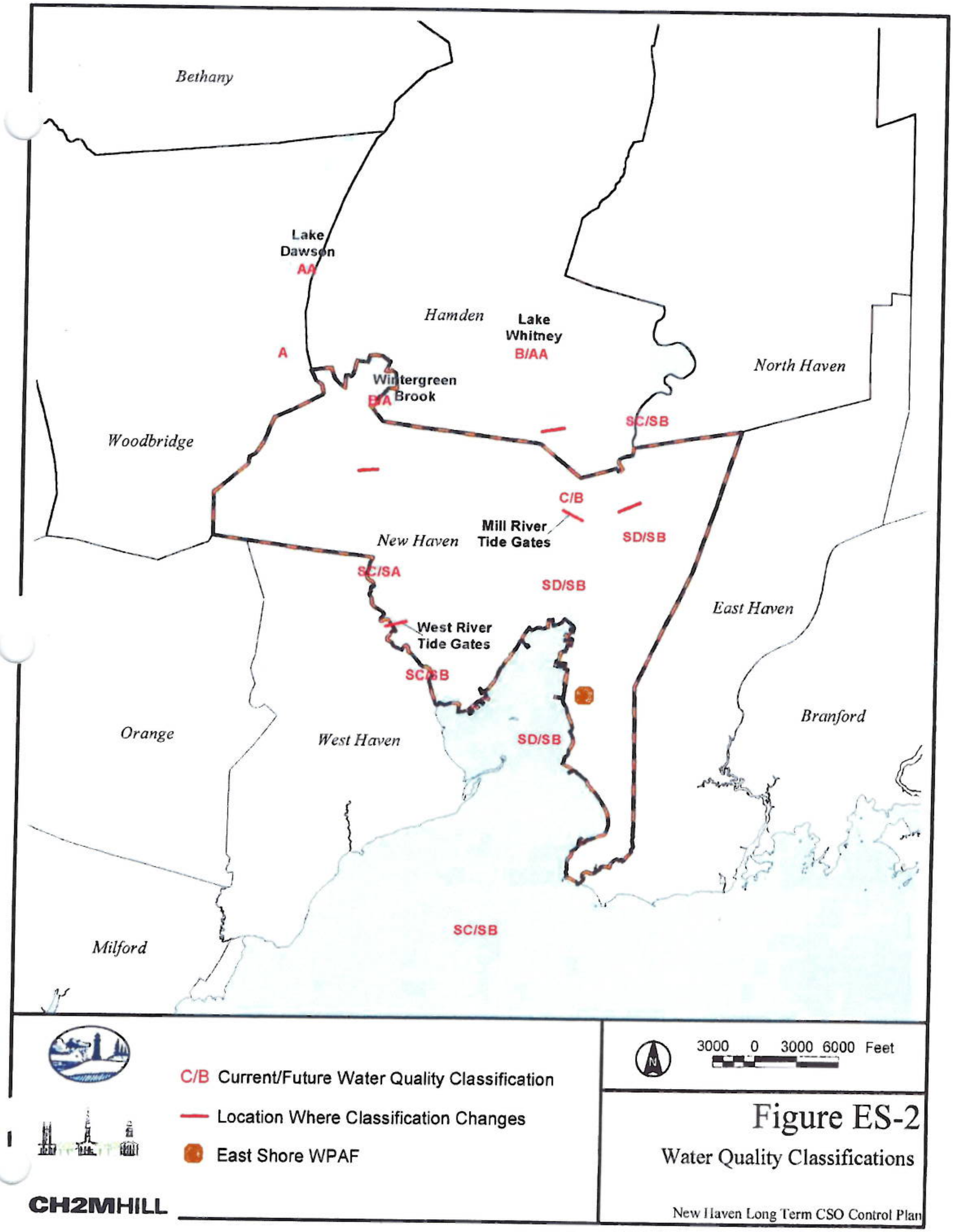


Figure ES-2

Water Quality Classifications

New Haven Long Term CSO Control Plan

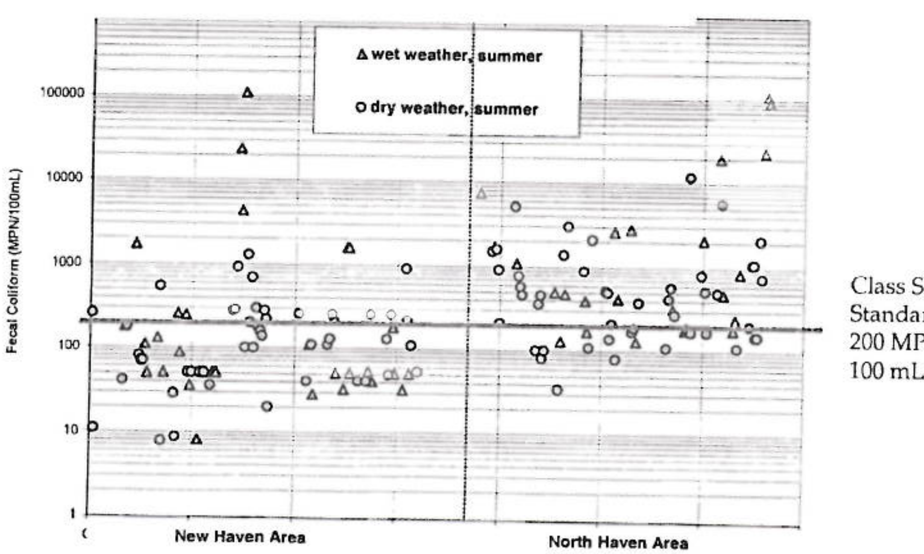
influenced by sources of pollution which are not readily correctable receive C or D classifications. Several of New Haven's rivers and the harbor are currently classified as C or D waters.

CTDEP's classification system is supported by both numeric and non-measurable criteria. Numeric water quality standards are used for Classes AA, A, B, SA, and SB waters. These criteria include coliform bacteria, dissolved oxygen, pH, temperature, turbidity, and chemical constituents. Other parameters are judged by qualitative and aesthetic assessments. These parameters include color, surface solids, suspended solids, silt, taste, and odor. From this list, five parameters were selected to support the evaluation of CSO impacts and control alternatives because they are reflective of the overall water quality and are present in CSOs. These parameters include bacteria (fecal coliform, FC), biochemical oxygen demand (BOD), total suspended solids (TSS), nitrogen, and dissolved oxygen (DO). CTDEP uses numeric criteria for bacteria to determine the sanitary quality of the water and its support of swimming and shellfishing uses. BOD is an indicator of organic contaminants. TSS is frequently used as a surrogate for a wide variety of pollutants that may impact sediments and cause long-term health problems. Nitrogen was selected based on the interests of the Long Island Sound Program and their goals for controlling nutrient loads to the Sound. CTDEP also uses numeric criteria for DO as a direct measurement of each water body's health and ability to support aquatic life.

Review of Available Water Quality Data

A library of water quality data was developed for the Quinnipiac, Mill, and West Rivers and New Haven Harbor. The library was formed from data previously collected by a broad group of local, state, and federal water quality surveys conducted between 1974 and 1998. These data were evaluated to identify general water quality characteristics upstream of New Haven, within New Haven, in dry and wet weather, in winter and summer, and over time. Conclusions from the reviews indicate that each of the rivers and the harbor are influenced by pollutants from CSOs, urban stormwater discharges, upstream sources, and local municipal or industrial point sources. As shown in Figure ES-3, data collected on the Quinnipiac River upstream of New Haven demonstrated frequent violations of the CTDEP's

FIGURE ES-3
Quinnipiac River, Fecal Coliform Data



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bacteria standards in wet and dry weather. Other data collected from the Quinnipiac River demonstrate that nitrogen concentrations coming into New Haven exceed traditional standards for healthy water bodies. Data collected on the Mill and West Rivers demonstrate generally acceptable water quality upstream of New Haven. Although not entirely reflective of current conditions, these data also demonstrate that CSO and urban stormwater discharges within the City of New Haven have the potential to cause violations of bacteria standards and other adverse impacts to water quality. Although still problematic, bacteria concentrations collected from New Haven Harbor show a significant trend toward improvement.

Contributions to Existing Receiving Water Quality

Within New Haven the primary factors influencing receiving water quality are pollutant contributions from upstream river flow, stormwater, CSOs and the East Shore WPAF. To estimate the relative contribution of each source, the inputs from surface waters entering the study area and the WPAF were estimated using historic data. The contributions from CSOs and stormwater were estimated from models of the New Haven sewer system and drainage area for an average rainfall year. The event mean pollutant concentration (EMC) from each source was estimated from data collected in New Haven and urban areas with comparable stormwater runoff characteristics. While the rivers contribute more flow than CSOs, stormwater, or the WPAF (Table ES-1), river pollutant concentrations are substantially lower than those from other sources (Table ES-2). The concentrations found in stormwater and CSOs are highest for all water quality parameters evaluated, and the coliform levels typically present in CSOs are at least 100 times greater than the concentrations estimated for other sources.

TABLE ES-1
Flow Volume Summary for the Average Year, Baseline Conditions (MG)

Flow Source	Quinnipiac River	Mill River	West River	New Haven Harbor
River Inflow	46,830	15,160	6,690	71,010
CSO	60	40	80	60
Stormwater	580	310	1,260	960
East Shore WPAF	—	—	—	11,500
Total	**47,470**	**15,510**	**8,030**	**83,530**

The contribution of pollutants to the surface waters is not equally distributed among the CSOs. The eight largest CSOs account for about 90% of the annual discharge volume, and the smallest ten CSOs make up less than 1% of the total CSO discharge (see Figure ES-4). The city-wide average overflow volume is about 0.4 million gallons per event, with the largest CSOs averaging about 1 million gallons and the ten smallest CSOs averaging less than 0.1 million gallons.

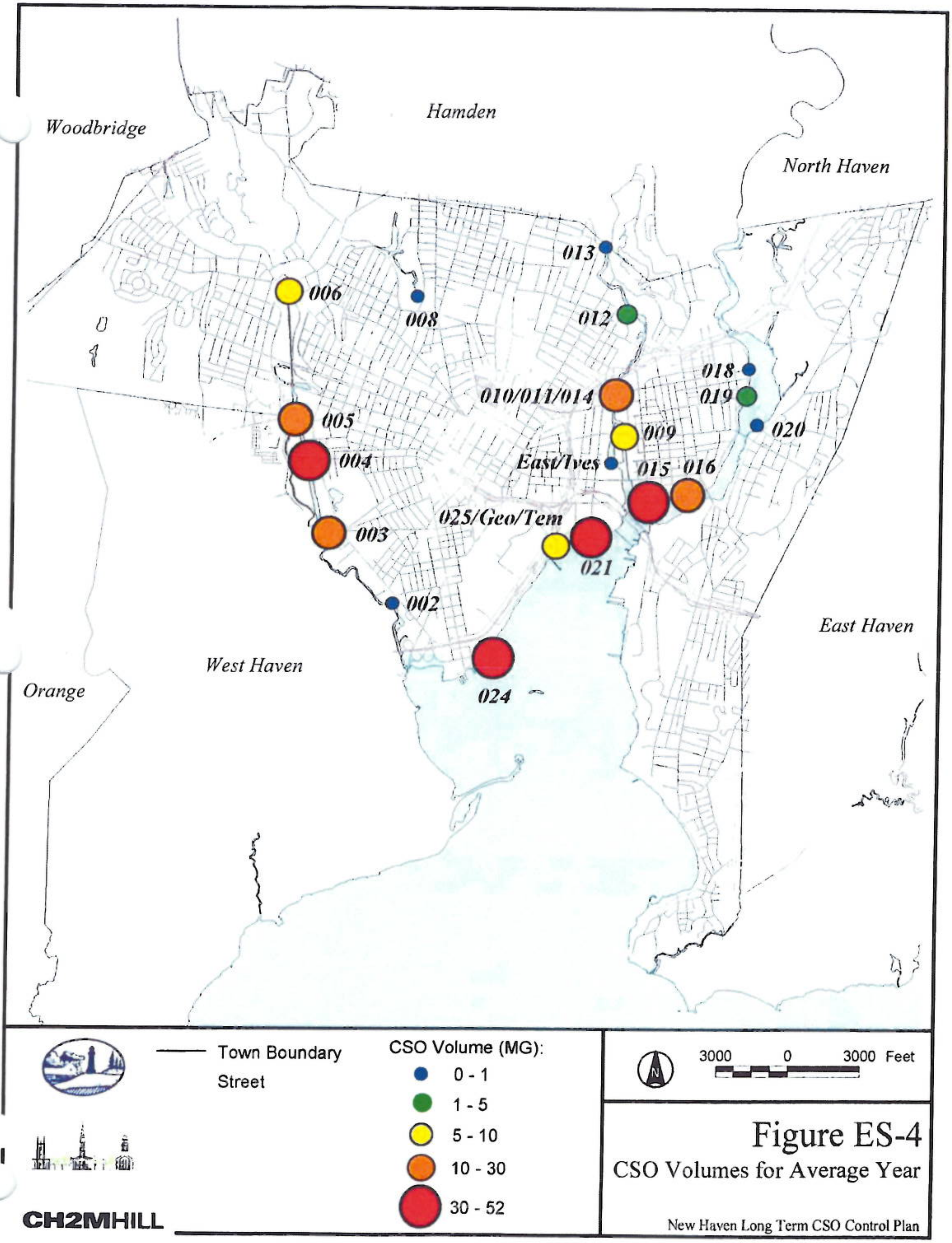

Figure ES-4

CSO Volumes for Average Year

New Haven Long Term CSO Control Plan

TABLE ES-2
Summary of Pollutant Event Mean Concentrations for Pollutant Loading Model Input

Pollutant Source	BOD (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	TN (mg/L)
Quinnipiac River Inflow	3.5	56.5	1700	5.7
Mill River Inflow	3.1	15	130	0.3
West River Inflow	3.5	15	15	0.3
CSO	75	150	1,000,000	21
Stormwater	50	50	10,000	3
WPAF Effluent	8.1	11.6	8.1	9.3

The total volume of CSO discharges to New Haven's receiving waters is relatively low, especially in comparison to conditions seen in other northeastern United States cities. CSO input to the surface waters in New Haven is overwhelmingly dominated by less than half the individual outfalls.

Pollutant Loads

Table ES-3 presents a comparison of pollutant loads to the various New Haven receiving waters based on average annual river flows and CSO, stormwater, and WPAF discharges.

The data indicate a range of receiving water impacts. High BOD loads are often associated with large volumes of stormwater discharges. High fecal coliform loads are often associated with large volumes of CSO discharges. High TSS and TN loads result from a variety of sources. Conclusions about pollutant loadings for each receiving water are presented below.

TABLE ES-3
Summary of Annual Pollutant Loads

Receiving Water	BOD (pounds)	TSS (pounds)	Fecal Coliform (10^{12} MPN)	TN (pounds)
Quinnipiac River	1,679,000	22,318,000	5,620	2,225,000
Mill River	543,000	2,076,000	1,595	46,200
West River	770,000	1,460	3,484	59,000
New Haven Harbor	4,367,000	27,810,000	14,861	3,340,000

Quinnipiac River

- Upstream sources deliver a significant pollutant load annually—the river regularly exceeds water quality standards for FC during both dry and wet weather

- CSOs, particularly 016 and 015 which are near popular fishing areas, are a significant source of FC during wet weather
- Elimination of CSOs within New Haven will not bring the FC concentrations into compliance; control of other pollutant sources such as upstream sources and stormwater will likely be needed
- New Haven stormwater discharges are a significant source of BOD loads
- Upstream sources and New Haven sources both contribute significantly to TSS and TN loads during wet weather

Mill River

- Upstream waters (at Lake Whitney) meet most water quality standards
- There are significant impacts from CSOs and/or urban stormwater upstream of the New Haven city limits
- Limited data indicate violations of FC standards during both dry and wet weather
- Sewer separation in the Mill River watershed did not eliminate CSOs
- CSOs, particularly 011, are the most significant pollutant source during wet weather
- CSO 012, although relatively small in volume (and therefore pollutant load), is the most significant CSO in the more sensitive areas upstream of the tide gates
- Elimination of CSOs may not bring the FC concentrations into compliance; control of other pollutant sources such as upstream sources, and particularly stormwater, may also be needed

West River

- Upstream waters meet most water quality standards
- There are significant impacts from CSOs and urban stormwater in New Haven
- CSO 004 had the third largest overflow volume during the average year simulation and was active for significantly longer periods than other CSOs
- Limited data indicate violations of FC standards during both dry and wet weather
- CSOs, particularly those located upstream of the tide gates in the most sensitive areas, are the most significant pollutant source during wet weather
- Elimination of CSOs may not bring the FC concentrations into compliance; control of other pollutant sources such as upstream sources, and particularly stormwater, may also be needed
- New Haven stormwater discharges deliver significant BOD, TSS, and TN loads during wet weather

New Haven Harbor

- Limited data indicate violations of FC standards during both dry and wet weather
- Trends in FC data demonstrate significant improvement over time
- Upstream sources, particularly the Quinnipiac River, are the most significant pollutant sources during both dry and wet weather
- Elimination of CSOs may not bring the FC concentrations into compliance; control of other pollutant sources—particularly stormwater—may also be needed
- New Haven stormwater discharges deliver significant BOD and TSS loads during wet weather
- Although the WPAF consistently meets permit limitations and provides a substantial pollutant load reduction (particularly for FC), the effluent delivers over 20% of the significant BOD load and 30% of the TN load to the harbor

Summary

Water quality data collected on the Quinnipiac, Mill, and West Rivers and New Haven Harbor demonstrate that each of these receiving waters has uses that are not fully supported by existing water quality. These impairments are caused by a combination of CSOs, urban stormwater discharges, upstream sources, and local municipal or industrial point sources. The West River was identified as being the receiving water most impacted by CSO discharges, followed by the Mill River, the Quinnipiac River, and New Haven Harbor; therefore, control of the New Haven CSOs should be ranked in a similar fashion. The pollutant load from CSOs is dominated by a few individual discharges, and the discharge volumes from even the largest CSOs are small compared to those in other urban areas. New Haven does not have the authority to control discharges from upstream sources into New Haven's receiving waters; therefore, the City must focus on their own CSO and stormwater discharges. It is important to note that New Haven stormwater discharges are significant pollutant sources and may also require control before water quality standards can be met.

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Acronyms

BOD	biochemical oxygen demand
COD	chemical oxygen demand
CSO	combined sewer overflow
CT DA/BA	Connecticut Department of Agriculture, Bureau of Aquaculture
CTDEP	Connecticut Department of Environmental Protection
DO	dissolved oxygen
EMC	event mean concentration
FC	fecal coliform
IDF	intensity, duration, frequency
LISP	Long Island Sound Program
MG	million gallons
mgd	million gallons per day
MPN	most probable number
NPDES	National Pollution Discharge Elimination System
NURP	Nationwide Urban Runoff Program
SCCRWA	South-Central Connecticut Regional Water Authority
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WPAF	East Shore Water Pollution Abatement Facility
WPCA	Water Pollution Control Authority
WPCP	West Haven Water Pollution Control Plant

SECTION 1

Introduction

Project Background

The City of New Haven and the New Haven Water Pollution Control Authority (WPCA) operate a wastewater collection and treatment system that serves more than 100,000 residents of New Haven, and through interlocal agreements, the Towns of Woodbridge, Hamden, and East Haven. (East Haven accepts some wastewater flow from North Branford.) The wastewater collection system includes both combined and separate sewers. A combined sewer is one that collects both sanitary sewage and stormwater runoff. In a separated sewer system, one sewer collects sewage and another collects stormwater runoff.

During dry weather, New Haven's sewer system conveys a combination of sanitary flow and groundwater infiltration to the 40-mgd East Shore Water Pollution Abatement Facility (WPAF). All dry weather flows undergo secondary treatment and disinfection at the WPAF before discharge to New Haven Harbor.

During wet weather, large quantities of stormwater enter the combined sewer system. As a result, parts of the system become overloaded, and combined sewage then overflows to receiving waters. There are roughly 244 miles of sanitary/combined sewers, 24 combined sewer overflow (CSO) regulators that divert high flows from the interceptor sewers to 20 CSO outfalls (CH2M HILL June 1998).

A facility plan that evaluated alternative methods for controlling CSOs was completed in 1981 and updated in 1988. The plan evaluated controls required to convey, treat, or store overflows associated with a 10-year storm. The plan concluded that sewer separation was the most cost-effective method of meeting the evaluation criteria. As of 1997, when the Long Term CSO Project began, approximately 35 percent of the planned sewer separation had been completed. Because of significant advances in regulatory requirements and technological issues, the city decided to reevaluate this approach.

Project Objectives

In 1997, the City of New Haven entered into an agreement with CH2M HILL to prepare a Long-Term CSO Control Plan. The objectives of the project as described in the agreement are to:

- Reduce the overall cost of constructing CSO controls
- Produce documents required for CSO-related issues described in the WPCA's National Pollutant Discharge Elimination System (NPDES) Permit, administered and enforced through the Water Management Bureau of the State of Connecticut Department of Environmental Protection's (CTDEP) Permitting, Enforcement, and Remediation Division (CTDEP 1994)

- Produce a long-term CSO control plan that is generally consistent with guidance provided in the USEPA's CSO Control Policy of April 1994

These goals were reviewed, expanded, and prioritized through the Stakeholders' review process during Tasks 1 and 6. The top evaluation criteria identified by the Stakeholders, in order of priority, were (CH2M HILL January 1999):

- Meet State water quality standards
- Protect critical areas
- Eliminate dry and wet weather overflows
- Maximize aquatic habitat
- Maximize conveyance
- Maximize treatment plant capacity

For additional information on goals, see Technical Memorandum #1, *Project Goals and Approach* (CH2M HILL June 1997) or Technical Memorandum #12, *Preliminary Evaluation of CSO Control Alternatives* (CH2M HILL January 1999).

Purpose of this Memorandum

As described in the preceding section, the highest priority goals identified by New Haven's Stakeholders are related to meeting water quality standards and protecting critical areas. To be successful, the LTCP project must identify CSO controls that, if possible, will support attainment of each receiving water's designated uses by compliance with water quality standards established by the CTDEP. To support the evaluation of CSO control concepts and their potential to meet goals established by the Stakeholders, a number of technical assessments related to each receiving water body and sources of pollution were completed. These assessments are documented in this report and are organized as follows:

- Identification of each water body's existing uses, sensitive areas, and general water quality characteristics;
- Identification of the water quality standards and designated uses established by CTDEP for each receiving water, and the status of compliance with these standards;
- Characterization of New Haven CSO activity and quantification of receiving water base flows;
- Identification of major categories of pollutants and the relative contribution of each; and
- Development of a ranking for each CSO in the City of New Haven based on its size, location, and potential to adversely impact water quality or limit use of a water body.

The data, results, and observations described in this report will be used as a foundation for the evaluation of CSO control concepts.

SECTION 2

Receiving Water Overview

This section presents an overview of the major receiving waters around New Haven. The overview includes a general description of each water body (location, size, and land uses), the receiving water uses (for example, boating, swimming or shellfishing), and sensitive areas (see definition below). A map is included for each water body that identifies the major features of the watersheds and shows where each use occurs. Lastly, a general statement of the historical and current pollutant sources in each water body is given.

As shown in Figure 2-1, the major receiving waters around New Haven include:

- Quinnipiac River
- Mill River
- West River
- New Haven Harbor

Turtle on the Mill River

Figure 2-1 presents a graphical overview of the watersheds. More detail on each water body is presented following the definition of sensitive areas.

Sensitive Areas

The EPA's National CSO Control Policy guidance documentation (USEPA, 1995), defines sensitive areas as follows, and notes that areas designated as "sensitive areas" should receive the highest attention for CSO control:

- Outstanding national resource waters
- National marine sanctuaries
- Waters with threatened or endangered species or their designated critical habitat
- Primary contact recreation waters, such as bathing beaches
- Public drinking water intakes or their designated protection areas
- Shellfish beds

Although not listed as an outstanding resource or marine sanctuary, the entire New Haven watershed drains to the Long Island Sound, which was designated an Estuary of National Significance in 1988. In addition, there was clear evidence of support for wildlife habitat and recreational opportunities during a series of field visits made during 1998.

Each of the receiving waters in New Haven contains some areas that are used for swimming although designated beaches exist only along the upper Quinnipiac River and New Haven Harbor. New Haven Harbor also contains shellfish beds. Based on these existing uses, these areas meet the EPA's definition of sensitive areas. The locations used for swimming and the locations of shellfish beds are shown Figure 2-1.

The CSO Policy guidance documentation also states that municipalities, in conjunction with state and federal agencies, may also identify specific areas as sensitive. Several areas on the

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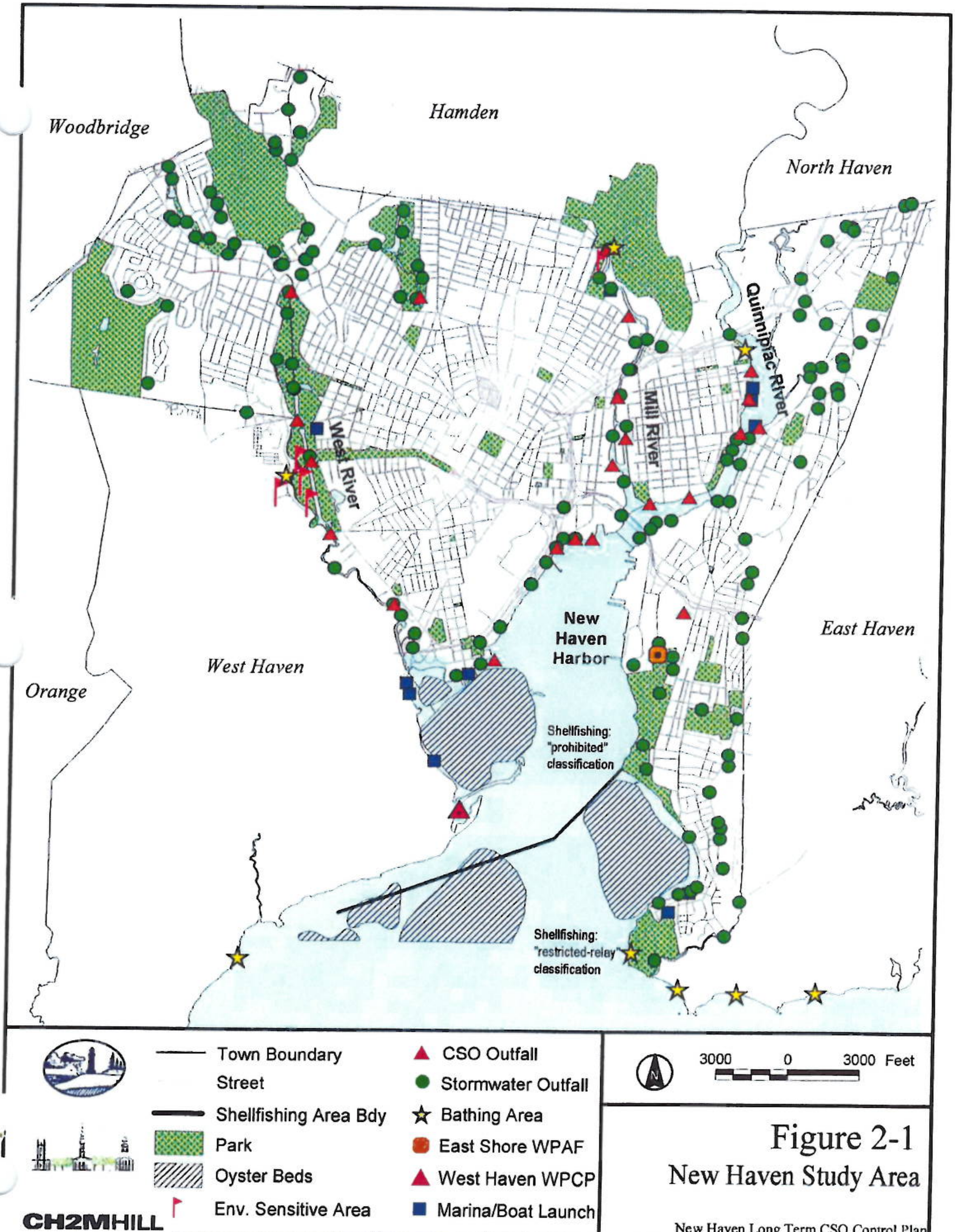
Woodbridge
Hamden
North Haven
Quinnipiac River
Mill River
West River
New Haven Harbor
East Haven
West Haven
Orange
Shellfishing: "prohibited" classification
Shellfishing: "restricted-relay" classification
Town Boundary
Street
Shellfishing Area Bdy
Park
Oyster Beds
Env. Sensitive Area
CSO Outfall
Stormwater Outfall
Bathing Area
East Shore WPAF
West Haven WPCP
Marina/Boat Launch
3000 0 3000 Feet
CH2MHILL
Figure 2-1
New Haven Study Area
New Haven Long Term CSO Control Plan

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West and Mill Rivers have been designated in this fashion. These areas were designated by the City's Parks Department and are also shown on Figure 2-1.

Sign in sensitive area along Mill River reading "Wildlife Area, Do Not Disturb"

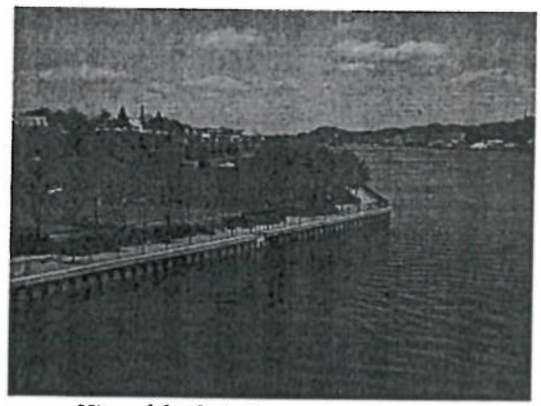
Lastly, although not fully supported by existing water quality, all of New Haven's receiving waters are designated by CTDEP for primary contact recreation as a future goal. Based on this goal, all of New Haven's receiving waters will meet the EPA's definition of sensitive areas in the future.

The receiving waters around New Haven are critical waterways, each with their own unique characteristics and pollution issues. The following subsections describe each of the receiving waters. Subsequent sections of this report present more detailed data on existing water quality, sources of pollutants, and the relative contribution of each pollutant source. In future reports, controls necessary to address water quality impairments related to CSOs will be identified.

Quinnipiac River

Overview

The Quinnipiac River originates in the town of Farmington and flows southward 38 miles through New Britain, Plainville, Southington, Cheshire, Meriden, Wallingford, North Haven, and Hamden before entering the study area in New Haven. From New Haven, it discharges into New Haven Harbor and the Long Island Sound. Major river tributaries are Eight Mile River, Southington; Ten Mile River, Cheshire; Harvor Brook, Meriden; and Muddy River, Wallingford. Two major impoundments on the river are Hanover Pond, Meriden, and Hamlin Pond, Plainville. Land uses within its 165-square-mile watershed range widely and consist of forested ridges, floodplain forest, farmland, urban and suburban residential areas, industrial development, and commercial districts. The lower reaches of the Quinnipiac are tidal. Salinity intrudes up to Sackett Point Road in North Haven, and the water surface elevation fluctuates 3 to 4 feet along the North Haven/New Haven boundary.



View of the Quinnipiac River north from Ferry Street Bridge

The Quinnipiac River is the largest river in the study and is the major tributary to New Haven Harbor. The section of river within the New Haven study area flows through a heavily industrialized area with an increasingly dense population. The river is bordered by marshes, an active sanitary landfill, and numerous industries, including petroleum companies and railways, along its banks. Historic buildings, businesses, and homes overlook the river on its eastern bank in the Fair Haven section of New Haven, whereas mostly urban and industrial areas border the western bank of the river.

Receiving Water Uses and Sensitive Areas

Public bathing is restricted on the Quinnipiac River to Dover Beach Park. Quinnipiac Park, Quinnipiac River Park, and Dover Beach Park along Front Street provide significant open recreational areas along the river as shown on Figure 2-2. There are two marinas, the Waucoma Yacht Club and Fair Haven Marina, on the western side of the river, and a boat launch at Clifton Street on the eastern side of the river.

Quinnipiac River Park, located along the Quinnipiac River's western bank

The Waucoma Yacht Club is adjacent to CSO 019, and the boat launch is adjacent to CSO 020. Fisherman can often be found fishing from the top of the outfall pipe at CSO 016 at Poplar Street and along the Quinnipiac Park area, near CSO 015. The proximity of CSOs to these active recreational uses is a public health concern.

Pollutant Sources

Extensive urbanization of the area has adversely affected river water quality. The Long Island Sound Study (LISP 1994) identified the Quinnipiac River as one of the river basins on the sound that should receive the highest priority for managing nonpoint sources of nitrogen. The study identified water quality impacts associated with high volume stormwater runoff as an important nonpoint source issue that still remains an issue today.

The number of direct river discharges has decreased dramatically since enactment of the Clean Water Act in 1972 (amended). Major river pollutant sources were identified in the 1994 CTDEP State Water Quality Report (305b Report) (CTDEP 1994) as industrial, municipal, and unspecified nonpoint discharges and minor sources identified as urban runoff, landfills, channelization, dam construction, and hydropower generation. Various stakeholders including the Quinnipiac River Watershed Association have identified trash and illegal dumping, poor land use planning, water diversion and over allocations, lack of habitat restoration, and lack of remediation of residual industrial pollution as activities that have detrimental effects on the river. Currently there are only six major direct industrial discharges and five wastewater treatment plant discharges. All the wastewater treatment plant discharges are upstream of the study area. As shown in Figure 2-2, there are 5 CSOs and at least 42 stormwater outfalls that discharge directly to the Quinnipiac River or indirectly via tributary drainage.

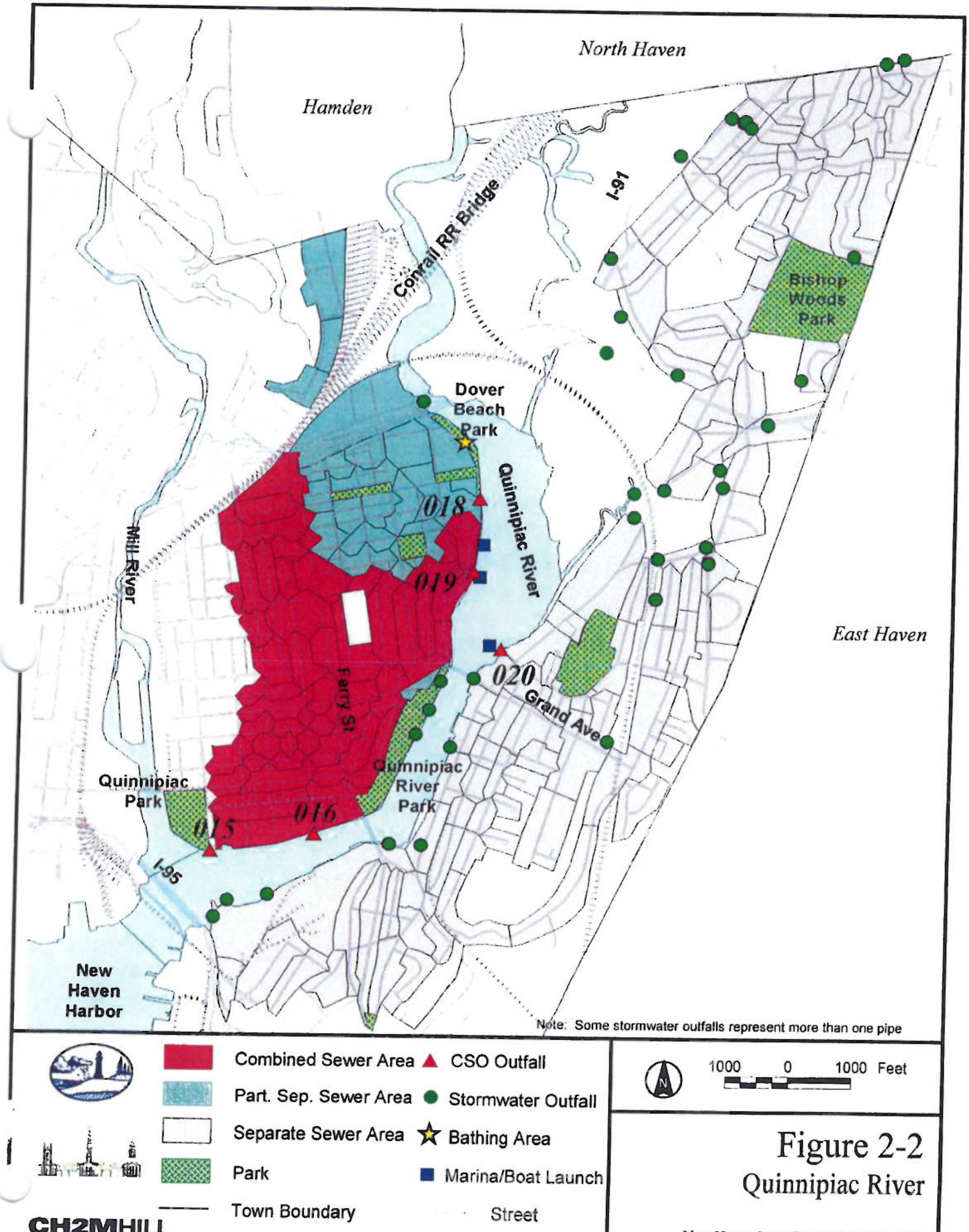


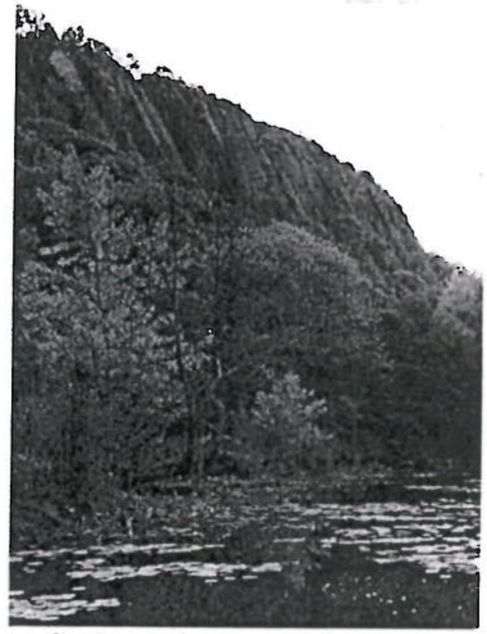
Figure 2-2
Quinnipiac River

New Haven Long Term CSO Control Plan

Mill River

Overview

The upper reaches of the Mill River are formed at the spillway of Lake Whitney dam in North Haven, CT. Until 1991, Lake Whitney served as a drinking water source for the Regional Water Authority (SCCRWA). The SCCRWA plans to bring the supply back on-line in 2004, and, therefore, the SCCRWA continues watershed management practices in the lake to maintain high water quality. At the spillway, the river is bordered on both sides by East Rock Park to the bridge at East Rock Road. South of East Rock Road, the river is bordered by stretches of vacant floodplain. Residential areas extend beyond the vacant floodplain until Interstate 91 crosses the river. From this point to the confluence with the Quinnipiac River at New Haven Harbor, the river is bordered by a combination of residential, commercial, and industrial development. The Mill River is much narrower than the Quinnipiac River. The river is tidally influenced; however, the river is mainly fresh water north of the tide gates at the Interstate 91 bridge crossing. The tide barrier is owned by the City of New Haven and operates automatically by high and low tide in the river.



East Rock Park, along the Mill River near the New Haven/Hamden border

Receiving Water Uses and Sensitive Areas

Pedestrian footbridge over Mill River, north of East Rock Road

The river supports quality wildlife habitat throughout the watershed to the tide gates near Willow Street (SCCRWA, 1999). Recreational uses in the upper reaches include canoeing with fishing at bridge crossings. As shown in Figure 2-3, the boat launch is located at the Orange Street bridge river crossing. There is also a popular bathing area by a pedestrian bridge that crosses the river just north of New Haven in neighboring Hamden. Quinnipiac Park is located near the confluence with the Quinnipiac River. Several environmentally sensitive areas north of New Haven in Hamden and one area in New Haven have been designated by the New Haven Parks Department. The proximity of CSO 013 to a pedestrian bridge and a bathing area upstream of an environmentally sensitive area is a water quality concern.

Pollutant Sources

Major river pollutant sources were identified in the 1994 CTDEP State Water Quality Report (305b Report) (CTDEP 1994) as CSOs and potentially threatening sources identified as urban runoff and river flow regulation and modification. As shown in Figure 2-3, there are 5 CSOs and at least 12 stormwater outfalls that discharge to the Mill River.

West River

Overview

The West River originates in the town of Bethany and flows south through Hamden, Woodbridge, Prospect, West Haven, and New Haven where it discharges into New Haven Harbor. A large section of the upper reaches of the West River are bordered by recreational areas consisting of Edgewood Park, the Yale University Bowl and Baseball Field, Allington Park, and Memorial Park. Just south of Memorial Park, Evergreen Cemetery borders the river on the east. South of the intersection between the river and Route 1 (at Orange Avenue), the river is bordered mostly by wetlands, vacant floodplain, and commercial areas.

Swans along the West River

Beaver Pond Park is an area of special importance within the West River Watershed because of its sensitive nature and its designated uses. It is located on the northeast side of the watershed, as shown in Figure 2-4. The park covers more than 100 acres (Diversified Technology Consultants June 1999) and receives flow from a watershed of approximately 1000 acres (about 20% of the West River Watershed).

Receiving Water Uses and Sensitive Areas

There is a boat launch on the east side of the river, off of Derby Avenue and E.T. Grasso Boulevard, just north of the large (60-inch high by 30-inch wide) and very visible CSO 004 at Legion Avenue. The boat launch area and the area just north of the Orange Avenue tide gates and CSO 003 are popular fishing areas. There is a noted swimming site in West Haven along the West River. Wild turkeys, swans, and other wildlife were seen throughout the waterway during field visits. North of Derby Avenue, the river becomes very shallow and debris begins to accumulate along the riverbanks and in the sediment, requiring frequent cleanups by park personnel. Several environmentally sensitive areas, identified on Figure 2-4, have been designated along the river by the New Haven Parks Department.

Fisherman displaying his catch along the West River

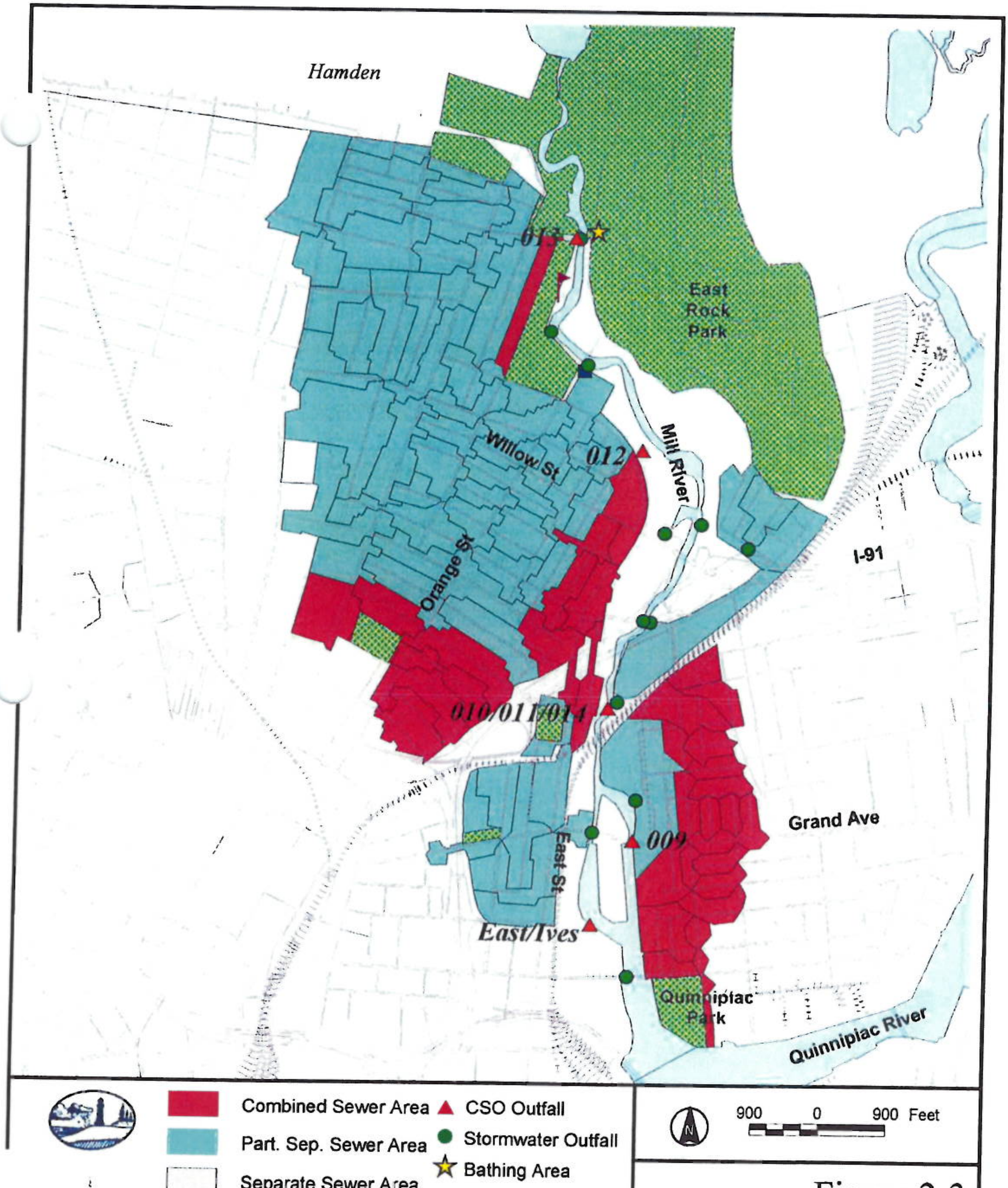


Figure 2-3
Mill River

New Haven Long Term CSO Control Plan

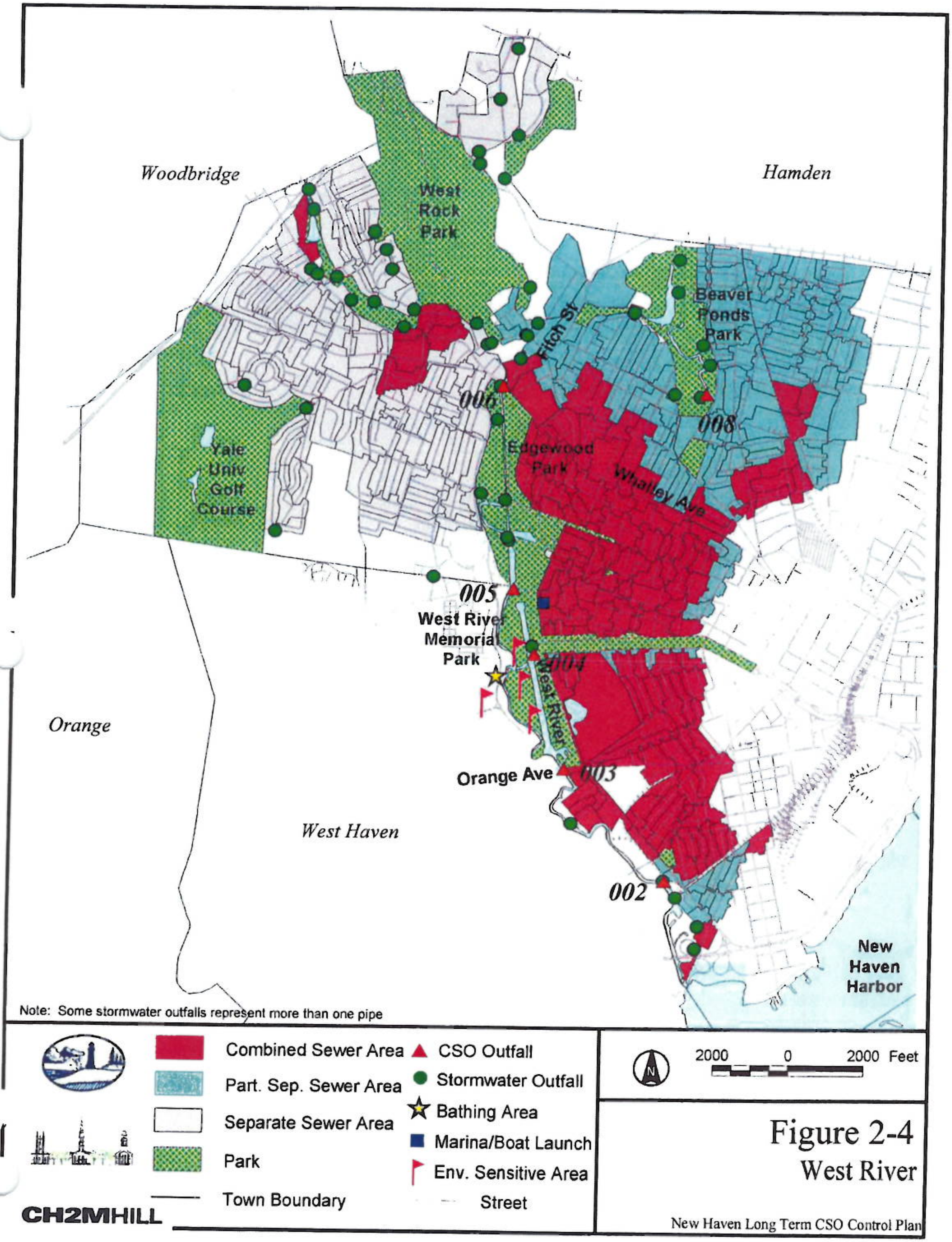


Figure 2-4
West River

New Haven Long Term CSO Control Plan

Beaver Pond Park includes ponds and wetlands and is the site of numerous recreational activities, including football, soccer, baseball, walking, jogging, and fishing (Diversified Technology Consultants June 1999).

Pollutant Sources

Point and nonpoint pollution sources and urban development over previous years have affected river course, flow, and water quality and ecology of the river. Major river pollutant sources were identified in the 1994 CTDEP State Water Quality Report (305b Report) (CTDEP 1994) as CSOs and urban runoff in addition to potentially threatening sources as river flow regulation and modification. According to the Long Island Sound Study (LISP 1993), the West River Watershed is designated as a high priority area for management of nonpoint sources of nitrogen and other contaminants due to the watershed's proximity to the sound in combination with a high density population.


West River near Legion Avenue and CSO 004

As shown on Figure 2-4, there are 5 CSO outfalls and at least 48 stormwater outfalls that discharge directly to the West River or indirectly via tributary drainage. The Legion Avenue CSO (004) has received a lot of attention due to 1) the outfall's visibility along the waterway; 2) its significant discharge activity; and 3) its discharge location to a segment of the river that is not flushed by upstream flows. Dry weather overflows have been observed in the past at this outfall. In early 1998, a period with dry weather overflows was ended with a modification to the regulator that raised the weir crests.

Sewer separation programs have already been implemented within the sub-watershed that contributes to Beaver Pond Park, diminishing the impacts to the Beaver Ponds from the one CSO that discharges there. The ponds receive their inflow mainly from stormwater, as there are at least 8 stormwater outfalls. A recent study indicated that concentrations in the ponds for some water quality parameters were low when compared to typical values for urban stormwater runoff, although they were higher than comparable measurements in rural ponds (Diversified Technology Consultants June 1999).

New Haven Harbor

Overview

New Haven Harbor is an embayment of the Long Island Sound. It is the most active commercial harbor in the State of Connecticut and one of the more heavily used harbors in New England. The major tributaries to the harbor are the Quinnipiac, Mill, and West Rivers, with a combined watershed of about 250 square miles. Two wastewater treatment plants discharge treated effluent directly to the harbor: the City of New Haven's East Shore

WPAF and the West Haven WPCP. Dense industrial and commercial areas border most of the harbor, the greatest concentration being at the mouth of the Quinnipiac River.

Receiving Water Uses and Sensitive Areas

Within the study area, four recreational areas border New Haven Harbor: Quinnipiac Park, East Shore Park, Fort Hale Park, and Lighthouse Park. Both Fort Hale Park and Lighthouse Park border Morris Cove. Four marinas, the West Cove Cooperative Marina, Shiners Cove Marina, West Haven Yacht Club, and Oyster Point Marina, are located on the west side of the harbor, and two marinas, the New Haven Yacht Club and New Haven Marina are located on the east side near Lighthouse Point. The beach at Lighthouse Park is the only designated public swimming area. Figure 2-5 also shows the location of numerous shellfish beds and their classification for use. Seed oysters harvested and relocated for contaminant removal during maturation from the harbor provide more than half of Connecticut's total oyster harvest.

New Haven Harbor view from Long Wharf

Pollutant Sources

The harbor has been the subject of a number of environmental reports. The major pollutant source to the harbor was identified in the 1994 CTDEP State Water Quality Report (305b Report) (CTDEP 1994) as municipal discharges. Minor pollutant sources included industrial discharges, combined sewer overflows, urban runoff, landfills, waste storage leakage, highway maintenance and runoff, in-place contaminants, and recreational activities. As shown on Figure 2-5, there are 3 CSOs that discharge directly to New Haven Harbor and 1 CSO (CSO 022) that discharges indirectly to the harbor via a ditch (Allen Place). In addition, there are at least 44 stormwater outfalls that discharge directly to the harbor or indirectly via tributary drainage.

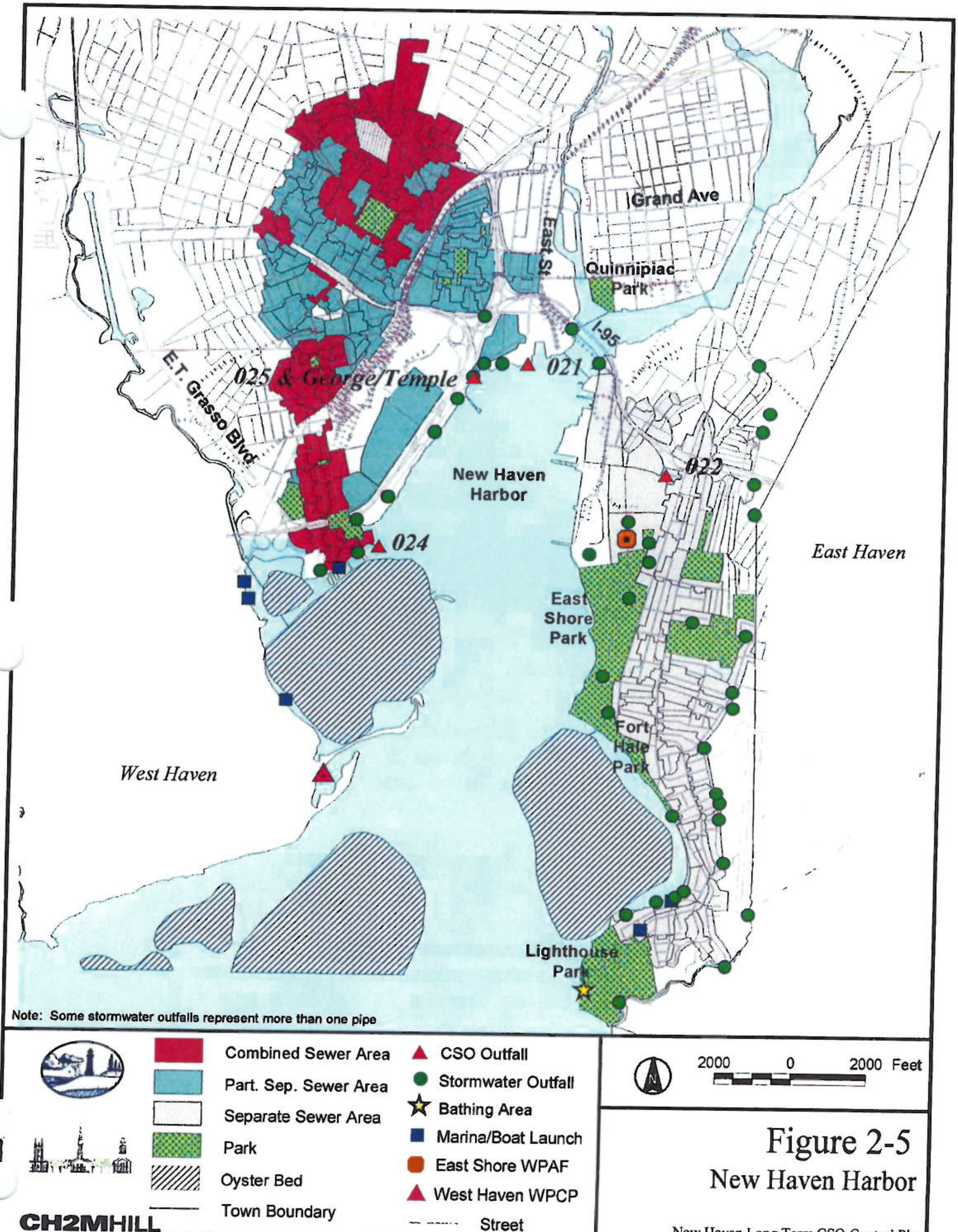


Figure 2-5
New Haven Harbor

SECTION 3

Receiving Water Quality

This section describes the water quality standards and designated uses for each of New Haven's receiving waters. It also presents an analysis of the water quality data that was used to identify where these standards are met, and where they are violated. This section describes:

- CTDEP water quality standards and designated uses
- Parameters selected for CSO planning
- Data sources used for this study
- Observed water quality in each of New Haven's receiving waters

The first section documents standards and uses established by the CTDEP. These discussions address existing water quality classifications, future classifications, and the uses supported by each classification (e.g., shellfishing or primary contact recreation). The numeric criteria are also listed for the water quality parameters for which limits have been established. Second, a discussion of the key water quality parameters is presented. This discussion documents the parameters selected for use in this project for CSO planning and the relative importance of each. The third section documents the data sources used for this study. The remaining sections describe water quality data gathered from the various sources for each receiving water. These data are presented and compared to numeric standards to determine which segments are in compliance and which are not. Comparisons are made of concentrations during wet and dry conditions where data were available. Trends over time are also investigated. Lastly, these same data are used to identify baseline concentrations for use in pollutant load calculations described in later sections of this report.

Water Quality Standards and Designated Uses

The CTDEP has established water quality standards and criteria for determining designated use classifications for surface and ground waters. The classification system developed includes goals for the restoration of water quality for all waters based on both numeric concentrations for measurable parameters and aesthetic and use criteria that are non-measurable parameters. Where existing water quality does not meet the designated use and water quality goals, the existing water quality is defined and followed by the restoration goal classification. As an example, SC/SB designates a water classification of SC, with the goal of attaining SB quality (though some parameters may be designated as unattainable). Inland surface waters are designated as AA and A through D, and marine waters are designated as SA through SD. State water quality classifications and designated uses associated with surface waters in the study area are indicated in Table 3-1. Figure 3-1 shows how each of the receiving waters in the study area have been designated.

Numeric water quality standards for Classes AA, A, B, SA, and SB exist for coliform bacteria, dissolved oxygen (DO), pH, temperature, turbidity, and chemical constituents. Other parameters are judged by qualitative and aesthetic assessments, including color, surface solids, suspended solids, silt or sand deposits, taste and odor, and benthic invertebrates present. Numeric water quality standards for fecal coliform and DO for both current classifications as well as restoration goal classifications for the waters in this study are indicated in Table 3-2.

TABLE 3-1
Connecticut Department of Environmental Protection Surface Water Quality Classifications

Water Quality Classification	Designated Uses
AA	Existing or proposed drinking water supply; fish and wildlife habitat; recreational use; agricultural, industrial supply and other purposes, (recreational uses may be restricted)
A	Potential drinking water supply; fish and wildlife habitat; recreational use; agricultural, industrial supply and other uses including navigation.
B	Designated uses for Class A with the exception of potential drinking water supply.
C	Water quality designated uses and criteria for Class B waters are not consistently achieved. Class C waters typically result from conditions that are correctable through management of point and nonpoint sources including urban runoff, combined sewer overflows and wastewater discharges.
D	Water quality designated uses and criteria for Class B are not achieved all or most of the time. Class D waters result from sources of pollution, which are not readily correctable such as contamination of sediments or out of state sources.
SA	Marine fish, shellfish and wildlife habitat, shellfish harvesting for direct consumption, recreation and other uses including navigation.
SB	Designated uses for Class SA, with the exception of shellfish purification, which is required prior to consumption.
SC	Water quality designated uses and criteria for Class SB waters are not consistently achieved. Class SC waters typically result from conditions that are correctable through management of point and nonpoint sources including urban runoff, combined sewer overflows and wastewater discharges.
SD	Water quality designated uses and criteria for Class SB are not achieved all or most of the time. Class SD waters result from sources of pollution, which are not readily correctable such as contamination of sediments or out-of-state sources.

Source: CTDEP, No Date.

TABLE 3-2
Dissolved Oxygen and Fecal Coliform Numeric Water Quality Standards

Classification	Water Quality Parameter	
	Minimum Dissolved Oxygen (mg/L)	Maximum Fecal Coliform (per 100 mL)[1]
AA	Not less than 5	100[2]
A	Not less than 5	100[2]
B	Not less than 5	200
SA	Not less than 6	14
SB	Not less than 5	200

[1] Standard based on geometric mean of sample group except Classes AA and A, which use arithmetic mean
[2] Criteria for Classes AA and A waters utilize a total coliform standard

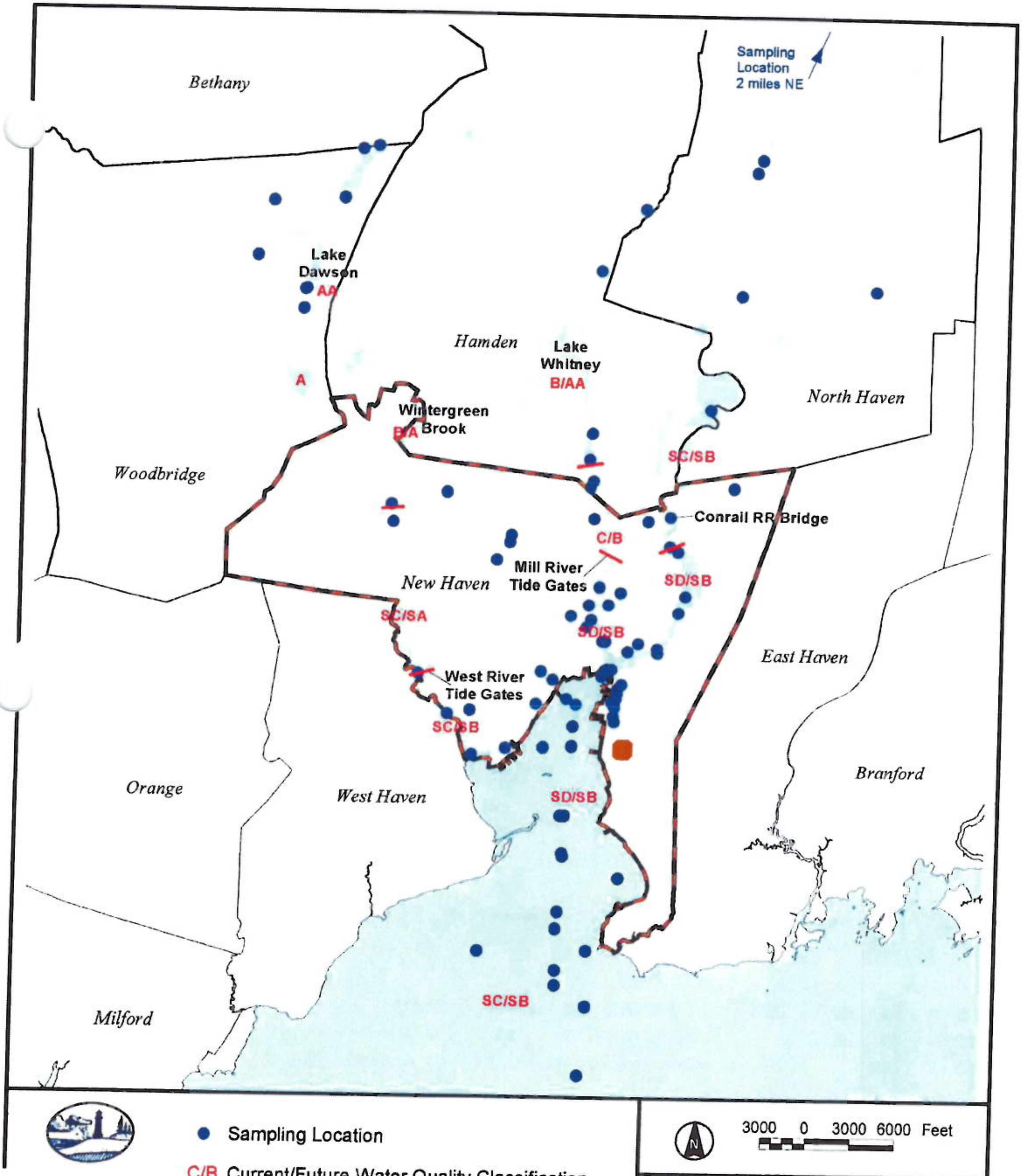


Figure 3-1

Water Quality Classifications and Sampling Locations

New Haven Long Term CSO Control Plan

Parameters Selected for CSO Planning

The water quality impacts associated with DO and fecal coliform as well as total suspended solids (TSS), nitrogen, and biochemical oxygen demand (BOD) were considered as part of the water quality evaluation. Concentrations for each parameter in CSO, stormwater, and wastewater treatment plant discharges are also presented in Section 5. Because CSOs discharge high flows on an intermittent basis and represent untreated mixtures of sanitary waste, stormwater runoff, and industrial process wastewater, they pose a more concentrated and potentially greater threat to public health and the overall environmental health of the receiving waters. Water quality violations caused by CSO discharges are typically from fecal contaminants, and to a lesser degree from BOD and TSS loads. However, CSO discharges also represent sources of metals, nutrients, and organics. Previous studies similar to the New Haven Long Term CSO Plan have supported these observations. Data from a study in Providence, Rhode Island, are provided in Table 3-3 (Louis Berger & Associates 1998). Fecal coliform concentrations measured in CSO discharge greatly exceeded concentrations in source waters and wastewater treatment plant effluent. In contrast, wastewater treatment plant effluent contributes significantly more TSS and BOD than do CSO discharges.

TABLE 3-3
Relative Annual Loads to the Providence River/Upper Narragansett Bay

Parameter	Percent of Total Annual Load		
	CSO	WWTF	Rivers and Urban Stormwater
Flow	1	9	90
Fecal Coliform	92	0	8
Total Suspended Solids	15	40	45
Biochemical Oxygen Demand	16	43	41
Copper	6	25	69
Lead	13	30	57
Nickel	3	71	26
Nitrate	0.2	27	73
Ammonia	1	69	30
Phosphate	0.8	84	16

Source: Louis Berger & Associates 1998

The significance of each water quality parameter used in the current New Haven analysis is evaluated in the following paragraphs.

Bacteria

The State of Connecticut uses three bacterial indicators of pathogenic organisms associated with sewage contamination to determine: 1) the sanitary quality of the water bodies and 2) if the water bodies can support their designated uses. Total coliform is used as an indicator primarily of fresh water to determine its suitability as a drinking water source. Fecal coliform is a subgroup of total coliform and is used as an indicator primarily of marine waters to determine its suitability as a shellfishing resource. Enterococci are a subgroup of fecal coliform and are used as the preferred indicator to determine the quality of established bathing waters. Although there is a transition away from coliform as an indicator organism it is still used in monitoring programs to track long-term water quality trends. Bacteria standards vary from those indicated in Table 3-2 for designated shellfishing and bathing areas. For designated shellfish harvesting areas, fecal coliform organisms shall not exceed a geometric mean of 88 MPN/100 mL, nor shall more than 10 percent of the samples exceed 260 MPN/100 mL. For established bathing areas, enterococci shall not exceed a geometric mean of 33/100 mL, and no sample shall exceed 61/100 mL.

Biochemical Oxygen Demand

BOD is an indicator of the range of organic contaminants that could be present in CSO and stormwater discharges. Both municipal wastewater treatment plants and both separate and combined sewer overflows contribute large quantities of oxygen demanding material. Nonpoint sources, such as decaying aquatic vegetation, also contribute large quantities to most waters. Like nutrients, oxygen-demanding materials may accumulate in the benthos and slowly affect the overlying water long after the actual sources have been controlled.

Total Suspended Solids

TSS loadings are an indicator of a wide variety of pollutants, because many pollutants such as metals and oils adhere to floating particles. For this study, TSS will serve as a surrogate measure of such pollutants in CSO and stormwater discharges. Pollutants associated with TSS can accumulate in the receiving water sediments and contribute to long-term problems of toxicity and oxygen depletion. TSS loads typically are quantified in terms of total pounds per year of TSS released to the receiving water from all sources.

Nitrogen

Nitrogen is an essential nutrient for the growth of plants and protista. Excessive nitrogen loadings fuel algal blooms in receiving waters. When the algae die, the decomposition process consumes much of the available oxygen. This reduction in dissolved oxygen greatly affects aquatic life and habitats. The Long Island Sound Study has developed a Comprehensive Conservation and Management Plan to protect and improve water quality in Long Island Sound. Among the major problems that received special focus was hypoxia (low dissolved oxygen), which is primarily caused by the excessive discharge of nutrients such as nitrogen (USEPA July 1994).

Dissolved Oxygen

Dissolved oxygen requirements are important in evaluating conditions in New Haven's receiving waters because this parameter has been identified as the most widespread water quality impairment in the Long Island Sound. The Long Island Sound Study has found that low dissolved oxygen conditions seasonally impact wide areas along the western sound including New Haven Harbor and have been linked to excessive nitrogen loading. Loss of dissolved oxygen is a critical factor in water quality analysis and problems result when the demands exceed the ability of water bodies to entrain oxygen from the overlying air.

Data Sources

Data from existing sources were used to evaluate water quality characteristics for each of the receiving waters. No new data were gathered. The paragraphs below enumerate the data sources for the water quality data.

It should be understood that the quality assurance programs of these organizations are unknown. Moreover, details concerning the impact of exact sample locations (e.g., mixing zones) and times that the samples were taken relative to when and if there was a rainfall event are also unknown. These unknowns may affect the definition of "wet/dry" conditions and create general uncertainties. There are some limits as to what can be concluded concerning the data presented in this report. For the purposes of evaluating general water quality characteristics, the data are sufficient. For a more detailed analysis of temporal and spatial variability, the use of these data sets may not be sufficient.

South Central Connecticut Regional Water Authority

Water quality data collected from 1992 to 1996 by the SCCRWA at Lake Whitney and along the West River system were reviewed and incorporated into the CH2M HILL loading analysis (SCCRWA 1998).

USGS Database

Water quality information collected by the USGS (USGS 1984-1995) were reviewed for the two sampling stations closest to the study area on the Quinnipiac River in North Haven (1985 to 1995) and the New Haven Harbor (1984 to 1990).

New Haven Water Quality Survey

This survey (Metcalf & Eddy 1991) was conducted for the City of New Haven from July 1990 through October 1990. This study evaluated water quality in the New Haven Harbor and considered the effect on water quality exerted by loading from its tributary rivers, wastewater treatment discharges, and the influence on water quality exerted by the harbor sediments.

CTDEP Quinnipiac River Survey

This survey (CTDEP 1991) was conducted to collect chemical and physical data on the Quinnipiac River, to better characterize its water quality conditions, and to determine maximum pollution loadings. It consisted of primarily collecting multiple samples from selected locations and at known point source discharges over 24- or 48-hour periods during low or stable flow conditions. Parameters monitored for the Quinnipiac River study included dissolved oxygen, BOD, nutrients, and metals. Samples were collected at 10 stations from Hall Avenue in Wallingford to Forbes Avenue in New Haven. Only data collected within the study area at the Grand Avenue sampling station was reviewed.

CTDEP New Haven Harbor—Intensive Water Quality Survey

This survey (CTDEP 1974) was conducted to assess the significance of CSOs and wastewater treatment plants on water quality in the New Haven area. Sampling was conducted on July 29 and 30, 1974, at the East Street, East Shore and Boulevard wastewater treatment plants, the James Street Siphon Overflow, the West, Mill and Quinnipiac Rivers and inner and outer locations in the New Haven Harbor.

Annual Assessment of the Shellfish Growing Waters in New Haven

This assessment (CT DA/BA 1997) was conducted to update pollution sources and water quality data to ensure that the present shellfishing water classifications are in compliance with the Natural Shellfish Sanitation Program criteria.

Bureau of Aquaculture Database

Samples were taken in the lower Quinnipiac and in New Haven Harbor at nine different stations. Roughly eight samples were collected at each station per year (CT DA/BA 1990-1996).

Quinnipiac River

Water Quality Standards and Designated Uses

The current water quality classification for the stretch of the Quinnipiac River from the harbor to just beyond the I-91 bridge is SD, and the remaining upstream stretch within the study area is SC. These classifications indicate that the river segments are not fit for shellfishing or primary contact recreation although there is an active beach at Dover Beach Park.

Both stretches have designated future water quality classifications of SB. This classification allows shellfish harvesting with purification and primary contact recreation. The current and future classifications for the Quinnipiac River were indicated in Figure 3-1.

Water Quality

Existing water quality data were evaluated from four sources: USGS (1984-1995), Metcalf & Eddy (1991), CTDEP (1974), and CTDEP (1991).

Samples collected as part of the *Summer 1990 Water Quality Monitoring Program* were taken at the Grand Avenue Bridge during three dry weather events: July 17–18, September 4–5, and October 17–18. Seventeen to 20 samples were collected over the study period for each water quality parameter.

USGS data consists of roughly 130 samples collected for DO, fecal coliform, and TN from October 1985 through October 1997 in North Haven, CT. Samples were collected in both dry and wet weather.

The CTDEP *1991 Water Quality Assessment of Quinnipiac River* consisted of sampling at different locations on the lower river from September 9 to 11, 1991. No rainfall occurred during the sampling period and therefore the data were considered dry weather data.

Sampling conducted by the CTDEP on July 29 and 30, 1974, as part of the *New Haven Harbor—Intensive Water Quality Survey* consisted of six samples for each water quality parameter for both a wet and a dry weather event. Samples were collected at the Grand Avenue Bridge in New Haven and at Rt. 22 in North Haven.

The sampling locations for these studies were shown on Figure 3-1. Since the river is tidal in the lower reaches, contaminant concentrations in the river will be diluted as they begin to mix with harbor waters.

To establish background water quality characteristics for the Quinnipiac River, the source data is analyzed with respect to each of the pertinent parameters, namely fecal coliform, BOD, TSS, total nitrogen, and DO. For each water quality parameter, the water quality characteristics are discussed in relation to dry and wet weather and in relation to spatial variations between sections of the Quinnipiac upstream of and within New Haven. Data gathered from the Conrail Rail Road bridge just south of the Hamden border and upstream were considered to be data that define the water quality of the Quinnipiac in North Haven. Data collected from the Conrail Rail Road bridge to the New Haven Harbor are assumed to be data that define the water quality in New Haven.

Fecal Coliform

Table 3-4 presents select statistical parameters describing fecal coliform concentrations with variations in weather and sampling locations. It shows the variation of fecal coliform counts for dry and wet weather and for areas upstream and downstream of the North Haven/New Haven boundary.

TABLE 3-4
Fecal Coliform (MPN/100 mL)
Quinnipiac River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	10,702	2,676
	Median	2,800	1,100
	No. Samples	50	83
Within City of New Haven	Mean	46,100	420
	Median	2,400	280
	No. Samples	3	16

Note: Data obtained from CTDEP (1974, 1991), Metcalf & Eddy (1991), and USGS (1984-1995)
There is no standard for the current classification; however, the water quality goal is 200 MPN/100 mL.

The data are also plotted in Figure 3-2. There is a considerable amount of scatter and most fecal coliform measurements exceeded the state water quality classification of 200 MPN/100 mL for both Class B and SB waters during both dry and wet weather. The dry weather concentration is 25% of the wet weather concentration upstream of New Haven. Within the City of New Haven, the dry weather concentration is two orders of magnitude less than the wet weather concentration; however, these values are based on limited data. Additional data are plotted in Figure 3-3, showing variations between summer and winter data. Figure

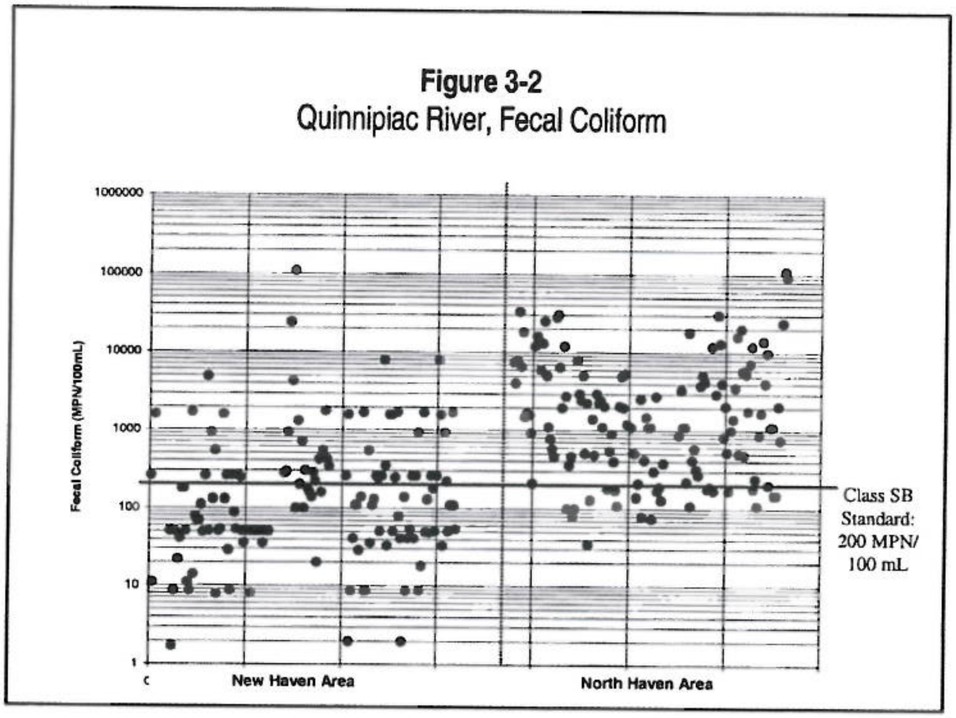


Figure 3-2
Quinnipiac River, Fecal Coliform
1000000
100000
10000
1000
100
10
1
Fecal Coliform (MPN/100mL)
New Haven Area
North Haven Area
Class SB
Standard:
200 MPN/
100 mL

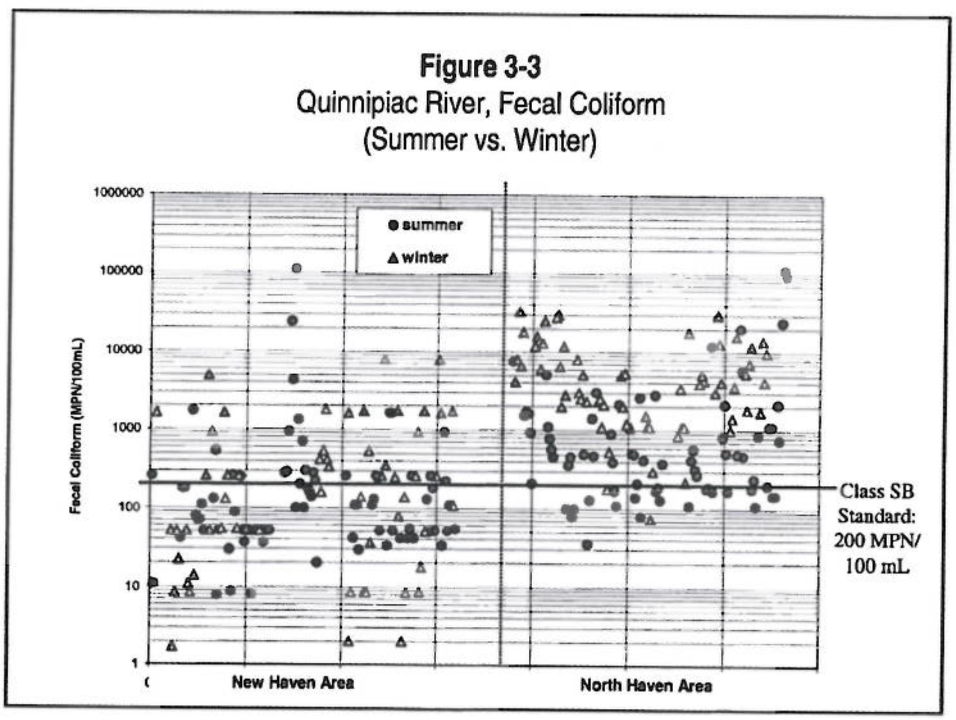


Figure 3-3
Quinnipiac River, Fecal Coliform
(Summer vs. Winter)
summer
winter
1000000
100000
10000
1000
100
10
1
Fecal Coliform (MPN/100mL)
New Haven Area
North Haven Area
Class SB
Standard:
200 MPN/
100 mL

3-3 shows the fecal coliform concentrations in the winter north of New Haven to be about an order of magnitude higher than summer concentrations. Within New Haven, the data are widely scattered. Figure 3-4 shows a decrease of at least two orders of magnitude in wet weather fecal coliform concentrations, although historical data are limited.

The drop in fecal coliform as waters enter New Haven from North Haven may be partly due to dilution. Waters from the upper reaches of the Quinnipiac will mix with the saline waters in the lower reaches of the Quinnipiac such that contaminant concentrations from North Haven will become diluted as they enter New Haven waters.

BOD

Table 3-5 presents select statistical parameters describing BOD concentrations with variations in weather and sampling locations. It shows the variation of BOD concentrations both for dry and wet weather and for upstream and downstream of the North Haven/ New Haven boundary. Figure 3-5 illustrates the data spread.

TABLE 3-5
Biochemical Oxygen Demand (mg/L)
Quinnipiac River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	3.2	3.5
	Median	2.7	2.35
	No. Samples	3	22
Within City of New Haven	Mean	1.1	2.7
	Median	0.6	2.0
	No. Samples	3	35

Note: Data obtained from CTDEP (1974, 1991), Metcalf & Eddy (1991), and USGS (1984-1995)
For comparison purposes, the WPAF's NPDES average monthly concentration limit is 30 mg/L (40 mg/L for wet weather).

There is little variation between concentration values upstream and downstream of the North Haven/New Haven City boundary. There are not enough data to quantify how BOD concentrations are impacted during wet weather.

TSS

Table 3-6 presents select statistical parameters describing TSS concentrations with variations in weather and sampling locations. It shows the variation of TSS concentrations both for dry and wet weather and for upstream and downstream of the North Haven/New Haven boundary. Figure 3-6 illustrates the data spread.

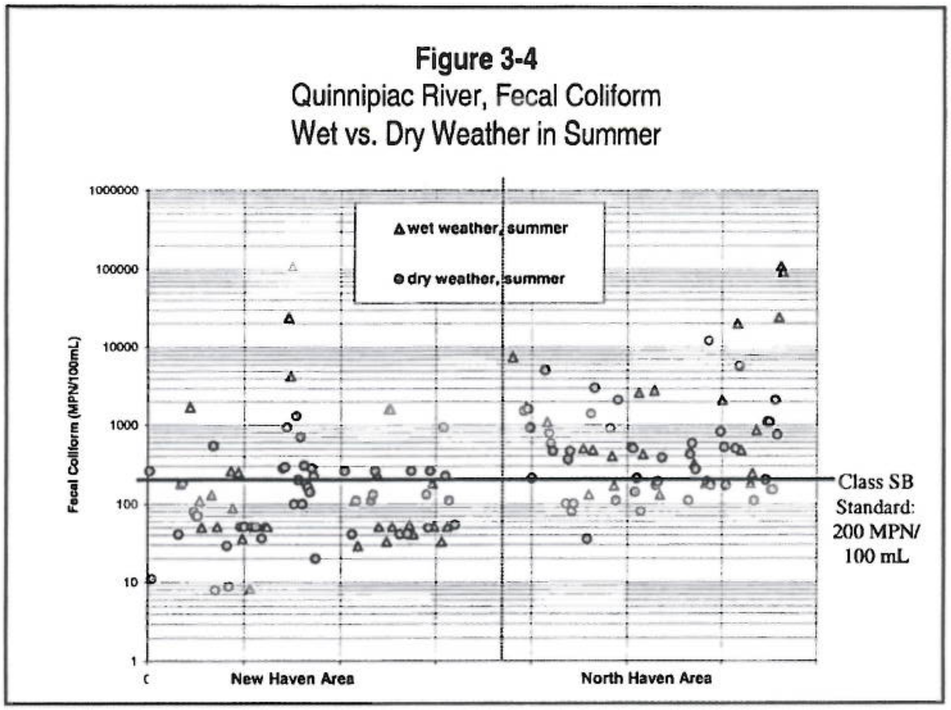


Figure 3-4
Quinnipiac River, Fecal Coliform
Wet vs. Dry Weather in Summer
wet weather, summer
dry weather, summer
Fecal Coliform (MPN/100mL)
1000000
100000
10000
1000
100
10
1
New Haven Area
North Haven Area
Class SB
Standard:
200 MPN/
100 mL

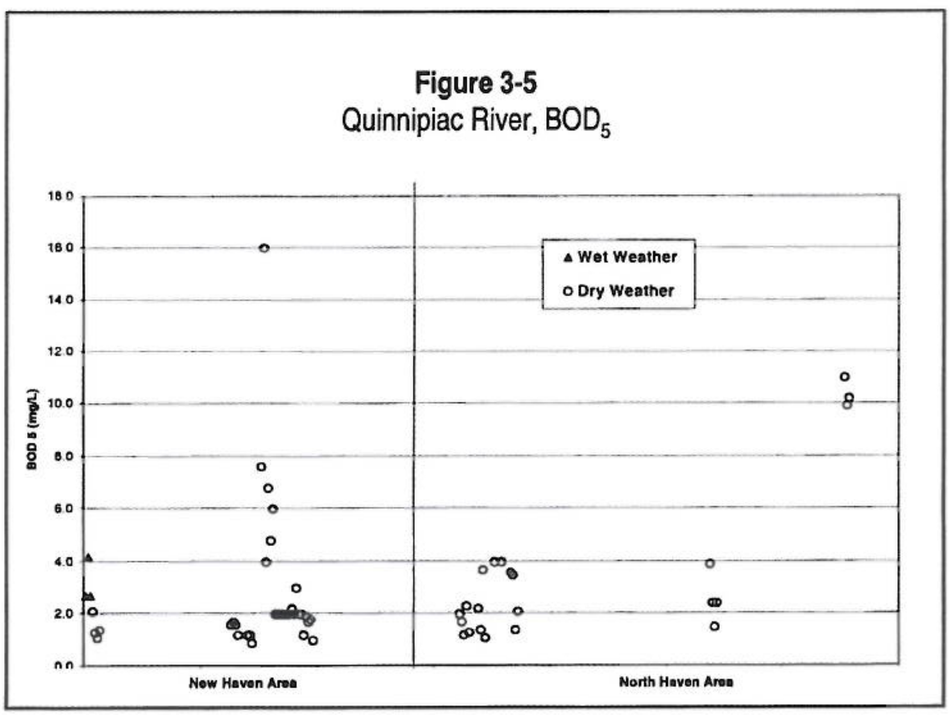


Figure 3-5
Quinnipiac River, BOD5
Wet Weather
Dry Weather
BOD 5 (mg/L)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
New Haven Area
North Haven Area

TABLE 3-6
Total Suspended Solids (mg/L)
Quinnipiac River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	—	56.5
	Median	—	56
	No. Samples	0	21
Within City of New Haven	Mean	—	75.9
	Median	—	73.5
	No. Samples	0	14

Note: Data obtained from CTDEP (1974, 1991)

As seen in Table 3-6, there are no data concerning TSS during wet weather. There appear to be more suspended solids in New Haven than in North Haven during dry weather. Since waters from the upper reaches of the Quinnipiac will mix with the saline waters in the lower reaches of the Quinnipiac, contaminant concentrations from North Haven will become diluted as they enter New Haven. However, instead of a decrease in concentration due to dilution, the data indicate an increase in concentration. Due to the limited availability of data, it is unclear why this increase occurs. Because of the age of the data set, this difference may no longer be accurate.

Total Nitrogen

Table 3-7 presents select statistical parameters describing total nitrogen concentrations with variations in weather and sampling locations. It shows the total nitrogen concentrations in the Quinnipiac; Figure 3-7 is a plot of the actual data.

There is little difference between wet and dry weather. However, as seen from Table 3-7, nitrogen concentrations are significantly lower in New Haven than in North Haven. This may be partially due to river water mixing with and being diluted by harbor water. Waters from the upper reaches of the Quinnipiac will mix with the saline waters in the lower reaches of the Quinnipiac such that contaminant concentrations from North Haven will become diluted as they enter New Haven waters. Although there are no regulations controlling nitrogen concentrations, it is generally believed that concentration levels greater than 0.5 to 1.0 mg/L may cause adverse affects in river systems.

Dissolved Oxygen

Table 3-8 and Figure 3-8 show the total dissolved oxygen concentrations in the Quinnipiac River. Table 3-8 presents select statistical parameters describing dissolved oxygen concentrations with variations in weather and sampling locations.

For the most part, state water quality standards of not less than 5 mg/L are met. The three samples in wet weather in New Haven were taken in 1974 and may not be representative of current conditions.

Figure 3-6
Quinnipiac River, Total Suspended Solids

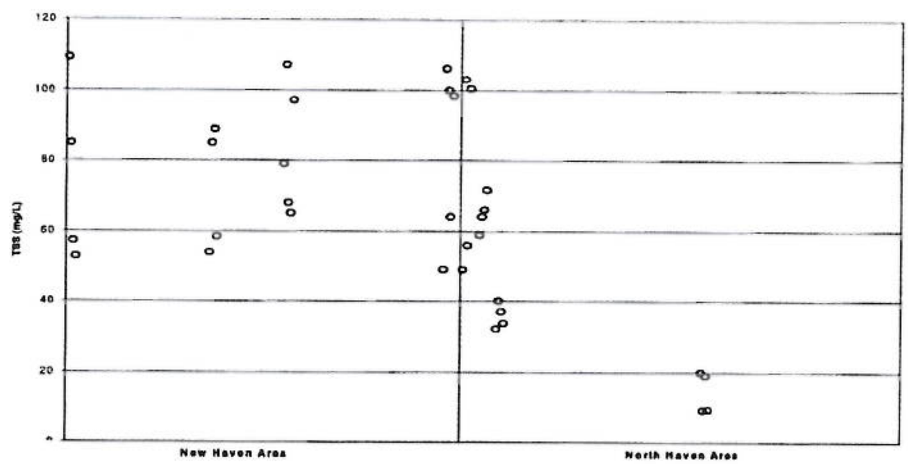


Figure 3-7
Quinnipiac River, Total Nitrogen

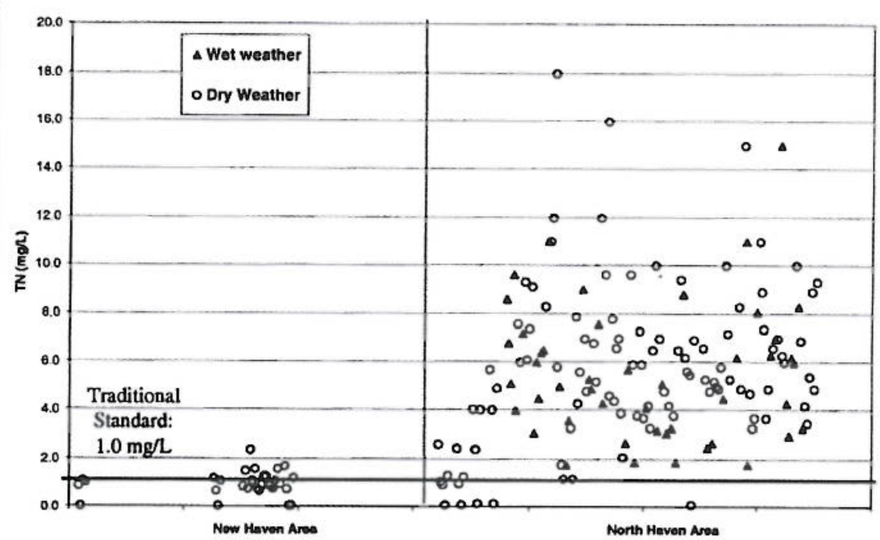


Figure 3-8
Quinnipiac River, Dissolved Oxygen

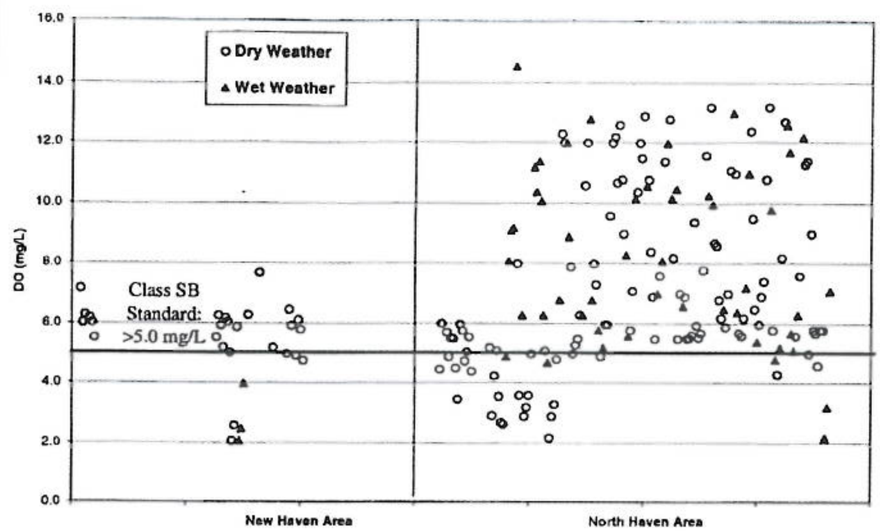


TABLE 3-7
Total Nitrogen (mg/L)
Quinnipiac River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	5.6	5.8
	Median	5.1	5.5
	No. Samples	43	106
Within City of New Haven	Mean	—	1.0
	Median	—	1.0
	No. Samples	0	31

Note: Data obtained from CTDEP (1974, 1991), Metcalf & Eddy (1991), and USGS (1984-1995)

TABLE 3-8
Dissolved Oxygen (mg/L)
Quinnipiac River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	8.3	7.2
	Median	8.1	6.0
	No. Samples	47	117
Within City of New Haven	Mean	2.9	5.6
	Median	2.5	5.6
	No. Samples	3	27

Note: Data obtained from CTDEP (1974, 1991), Metcalf & Eddy (1991), and USGS (1984-1995)
There is no standard for the current classification; however, the water quality goal is 5 mg/L.

Baseline River Concentrations

Concentration values used to characterize the Quinnipiac north of New Haven were chosen based on the data shown in Figures 3-2 to 3-8 and Tables 3-4 to 3-8. Because there was no significant difference between wet and dry weather, the values for BOD, TSS, TN, and DO concentrations are arithmetic averages of all measurements taken in North Haven during both dry and wet weather. The median value was chosen to represent baseline fecal coliform concentrations in the Quinnipiac since the fecal coliform data set is skewed positively. These data represent average conditions for both dry and wet weather concentrations.

Table 3-9 summarizes the baseline pollutant concentrations selected for the Quinnipiac as it enters the New Haven City boundary from North Haven. These concentrations are approximations for both dry and wet weather situations and are used for estimating average annual pollutant loadings from the Quinnipiac River upstream of New Haven.

TABLE 3-9
Baseline Pollutant Concentrations in the Quinnipiac River Upstream of New Haven

	TN (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	DO (mg/L)
Baseline Concentration	5.7	3.5	56	1700	7.5
Standard/Goal	1.0[1]	n/a	n/a	200[2]	5.0[2]

[1] Traditional standard to prevent adverse impacts
[2] State standard for Class SB waters

Mill River

Water Quality Standards and Designated Uses

The current water quality classification for the Mill River from the spillway at Lake Whitney to the river tide barrier is C, which indicates the water does not consistently meet the qualifications that would allow its use for recreation, agriculture, industry, or fish and wildlife habitat, although there are many active recreational uses of the river. The tidal waters of the Mill River from just upstream of the gates to the New Haven Harbor are currently designated SD. The SD classification defines this reach as being impacted by pollutant sources not readily correctable.

The designated future water quality classification from the spillway at Lake Whitney to the river tide barrier is B, with a future designation of SB for the tidal waters from just upstream of the barrier to the New Haven Harbor. Both classifications support uses such as fishing and primary contact recreation. The bounds of the water quality classifications were shown on Figure 3-1.

Water Quality

Existing water quality data was evaluated from four sources: Metcalf & Eddy (1991), USGS (1984-1995), CTDEP (1974), and SCCRWA (1999). The sampling locations were shown previously on Figure 3-1.

Most of the data were obtained from the *Summer 1990 Water Quality Monitoring Program*. Samples collected as part of that study were taken upstream of the tide gates in upper reaches near Lake Whitney spillway during three dry weather events: July 18–20, September 4–6, and October 17–18.

The USGS data consist of one sampling event at three locations in Hamden, CT, upstream of the New Haven border, on August 22, 1995. No rainfall occurred on that day, and, therefore, data were considered to be dry weather data.

The *New Haven Harbor—Intensive Water Quality Survey* included data collected on July 29 and 30, 1974, at three locations on the Mill River in New Haven: the Orange Street Bridge, the Lombard Street Bridge, and near the entrance to New Haven Harbor. Five to nine samples were collected for each water quality parameter for both dry weather (July 29) and wet weather (July 30) conditions.

The SCCRWA monitoring data were collected monthly at Lake Whitney and represent both dry and wet weather conditions. The monthly data were summarized as annual averages for 1992 through 1996.

To establish background water quality characteristics for the Mill River, the source data were analyzed in two ways. One analysis compared river water quality during wet and dry weather; the other compared water quality upstream of the New Haven border to water quality within the New Haven study area. Data gathered in and near Lake Whitney (Metcalf & Eddy 1991; SCCRWA 1999) and farther upstream in Hamden (USGS 1984-1995) define the water quality of the Mill River in Hamden (see Figure 3-1). Data collected from the Orange Street Bridge, the Lombard Street Bridge, and near the entrance to New Haven Harbor (CTDEP 1974) define the water quality of the Mill River in New Haven.

Fecal Coliform

Table 3-10 presents select statistical parameters describing fecal coliform concentrations with variations in weather and sampling locations. It summarizes fecal coliform concentration data in the Mill River for both dry and wet weather and for upstream and downstream areas of the New Haven/Hamden border. Figure 3-9 shows the actual data in the river. It can clearly be seen from the figure that the data representing New Haven are from the 1970's, while the data for upstream concentrations are more recent. Because of the amount of sewer separation that has taken place since the 1970's, the data for New Haven may not be representative of current conditions. The data taken from the SCCRWA were yearly averages and for comparative purposes, the data are considered to be dry weather data.

TABLE 3-10
Fecal Coliform (MPN/100 mL)
Mill River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	—	250[1]
	Median	—	100
	No. Samples	0	21
Within City of New Haven[2]	Mean	42000	22000
	Median	24000	9300
	No. Samples	9	9

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991), SCCRWA (1998), and USGS (1984-1995)
There is no standard for the current classification; however, the water quality goal is 200 MPN/100 mL.

[1] Given that Lake Whitney has previously been used as a drinking water source (and is again being considered for such a use), this number is a bit high (compare to Class B standard of 200 MPN/100 mL). The value may be due to the influence of urban wet weather discharges downstream of the dam but upstream of New Haven's boundary with Hamden.

[2] Data for New Haven are from 1974 and may not be representative of current conditions.

Similarly to the data examined for the Quinnipiac River, the fecal coliform concentration for wet data in New Haven is notably higher than for the dry weather data. This indicates the possible influence of CSO discharges on fecal coliform levels during wet weather events. All wet weather fecal coliform measurements and some of the dry data greatly exceeded the state water quality classification of 200 MPN/100 mL for class B waters. It should again be noted that the only wet weather data available for the Mill River were from the 1974 CTDEP survey. The wet weather data reflect one sampling event at three sites within the New Haven boundary.

There is also a significant difference in fecal coliform concentration between areas of the Mill River in New Haven and areas of the river in Hamden during dry weather. Since all data along the New Haven reach of the Mill River were gathered in 1974, these data represent water quality prior to implementation of recent sewer separation projects and sewer system improvements to eliminate combined sewer dry weather discharges. It is recommended to collect more data to show the benefits of recent projects and define the current water quality in the Mill River.

BOD

Table 3-11 presents select statistical parameters describing BOD concentrations with variations in weather and sampling locations. It summarizes BOD concentration data both for dry and wet weather and for upstream and downstream of the Hamden/New Haven boundary. Figure 3-10 shows the actual data spread. There is little variation between concentration values upstream and downstream of the Hamden/New Haven City boundary. Results here indicate there is little variation between dry and wet weather concentrations.

TABLE 3-11
Biochemical Oxygen Demand (mg/L)
Mill River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	—	3.1
	Median	—	2.6
	No. Samples	0	16
Within City of New Haven	Mean	2.7	3.9
	Median	1.5	2.1
	No. Samples	9	9

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991), SCCRWA (1998), and USGS (1984-1995) For comparison purposes, the WPAF's NPDES average monthly concentration limit is 30 mg/L (40 mg/L for wet weather).

TSS

There is one data point for TSS in the Mill River. The SCCRWA's sample showed a TSS concentration of 7.5 mg/L at Lake Whitney in 1995 (SCCRWA 2000). Literature values for TSS concentrations span a wide range, from 0.5 mg/L to 175 mg/L (Chapra 1996), with cleaner water bodies being at the lower end of the range (approximately 5–20 mg/L)

Total Nitrogen

There are no data concerning TN concentrations along the section of the Mill River within New Haven. However, the TN data upstream of New Haven are comprehensive. Table 3-12 summarizes the data, and Figure 3-11 shows the data spread. Table 3-12 shows select statistical parameters describing TN concentrations with variations in weather and sampling locations.

Although there are no regulations controlling nitrogen concentrations, it is believed that concentration levels greater than 0.5 to 1.0 mg/L may adversely affect river systems. Data gathered at upstream locations do not indicate potential nutrient problems; however, extensive algae blooms were noted during field visits upstream of the Orange Street bridge just south of Hamden.

Figure 3-9
Mill River, Fecal Coliform

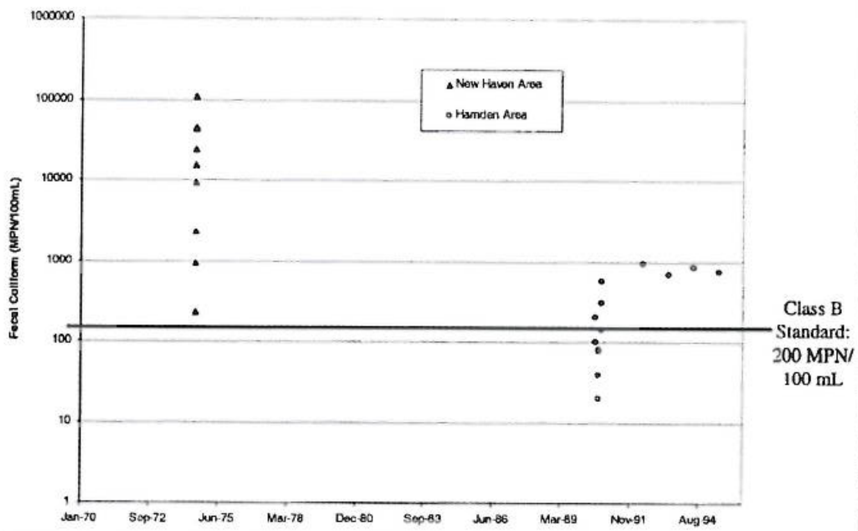


Figure 3-10
Mill River, BOD_5

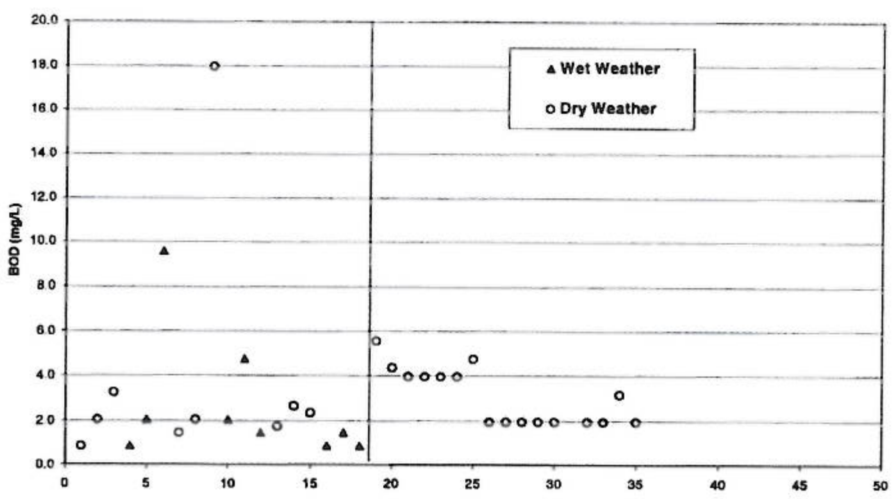


Figure 3-11
Mill River, Total Nitrogen
(Upstream of New Haven)

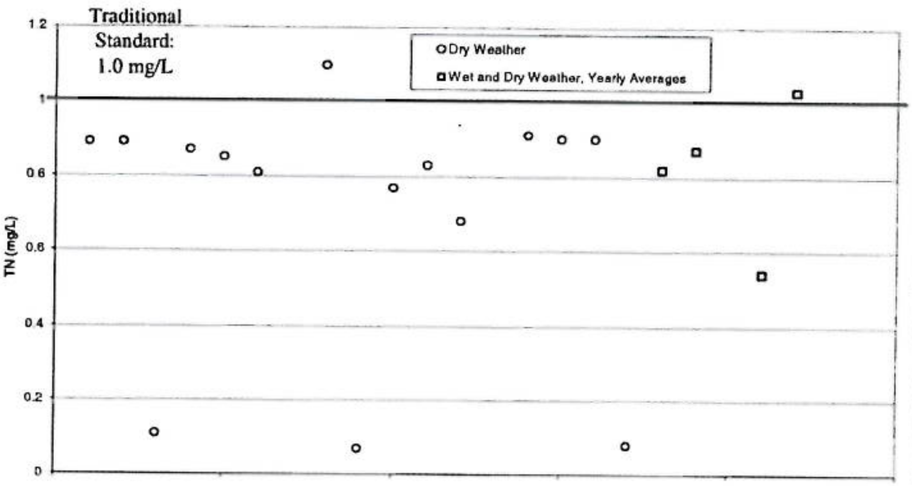
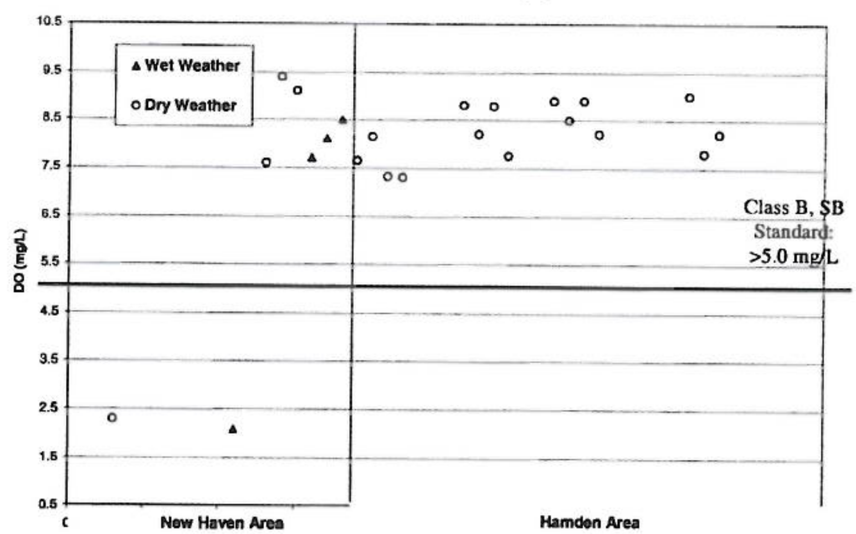


Figure 3-12
Mill River, Dissolved Oxygen



Dissolved Oxygen

Table 3-13 presents select statistical parameters describing DO concentrations with variations in weather and sampling locations. It summarizes DO data in the Mill River for both dry and wet weather and for upstream and downstream areas of the New Haven/Hamden border. Figure 3-12 shows the actual data in the river. Average DO levels in both wet and dry data sets meet the state water quality standard of not less than 5 mg/L for class B waters. As with the Quinnipiac River, there does not seem to be a problem with DO along the lower stretches of the Mill River.

TABLE 3-12
Total Nitrogen (mg/L)
Mill River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	—	0.73
	Median	—	0.85
	No. Samples	0	19
Within City of New Haven	Mean	—	—
	Median	—	—
	No. Samples	0	0

Note: Data obtained from Metcalf & Eddy (1991) and SCCRWA (1998)

TABLE 3-13
Dissolved Oxygen (mg/L)
Mill River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean	—	8.2
	Median	—	8.2
	No. Samples	0	15
Within City of New Haven	Mean	5.4	7.1
	Median	7.7	8.4
	No. Samples	5	4

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991), SCCRWA (1998), and USGS (1984-1995)
There is no standard for the current classification; however, the water quality goal is 5 mg/L.

Baseline River Concentrations

The average concentration value for all measurements taken in Hamden was selected to represent the average yearly water quality in the Mill River as it enters New Haven from

Hamden. Although the data represent only dry weather conditions, it is expected that they are reasonable approximations for both dry and wet weather situations in the Mill River in New Haven. As mentioned previously, the TSS data for the Mill River is limited to one data point. There is a wide range in literature values for TSS; a range given for the Potomac Estuary is 5-30 mg/L (Chapra 1996). In the Quinnipiac River, a baseline concentration of 56 mg/L was chosen based on the available data. A value of 15 mg/L was selected for use as a baseline value for the Mill River in this report. Estimated baseline concentrations for the Mill River are shown in Table 3-14.

TABLE 3-14
Baseline Pollutant Concentrations in the Mill River Upstream of New Haven

	TN (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	DO (mg/L)
Baseline Concentration	0.7	3	15	130	8
Standard/Goal	1.0[1]	n/a	n/a	200[2]	5[2]

[1] Traditional standard to prevent adverse impacts
[2] State standard for Class B/SB waters

There is little problem with BOD in the Mill River, and hence DO concentrations well exceed the state's minimum standard of 5 mg/L for natural surface waters. Nitrogen loadings from upstream sources may pose a potential problem, considering that concentration levels greater than 0.5 to 1.0 mg/L may cause adverse affects in river systems. An estimated value of 15 mg/L for TSS is fairly high but not likely to cause adverse effects.

West River

Water Quality Standards and Designated Uses

The current water quality classification for the West River from Lake Dawson (classified as AA) to the confluence with Wintergreen Brook (near the Whalley Avenue Bridge) is A, while that for Wintergreen Brook is B, which supports most activities except use as a drinking water source. Downstream of this point to the harbor, the river is classified as SC. River tide gates are located in this stretch just south of Orange Avenue. The SC classification indicates that the river segments cannot consistently meet the criteria for SB waters.

The future water quality classification for the West River between Lake Dawson and the confluence with Wintergreen Brook and for Wintergreen Brook is A, which supports use as a drinking water source. From the confluence downstream to the river tide gates, the river has a future classification of SA, which supports shellfish harvesting for direct consumption and primary contact recreation, among other uses. From the tidal gates to the river mouth, the future classification is SB, which would allow use for shellfish harvesting with purification and primary contact recreation. Water quality classifications on the West River are indicated in Figure 3-1.

Water Quality

Existing water quality data were obtained from three sources: Metcalf & Eddy (1991), CTDEP (1974), and SCCRWA (1999). Data upstream of New Haven in the Town of Woodbridge were obtained from the SCCRWA (1999). Samples used in this report were taken from the years 1992 to 1998. Samples were collected at six locations, with most of the data coming from two of those locations. At those two locations, samples were collected once or twice a month. Most of the water quality data for the West River within the City of New Haven come from Metcalf & Eddy (1991) and were collected from July 1990 through October 1990. Fourteen to 18 samples were collected just upstream of the tide gates during three dry weather periods: July 17–18, September 4–5, and October 17–18. Data collected by the CTDEP (1974) at the Spring Street Bridge on July 29 and 30, 1974 consisted of three samples for each water quality parameter for both dry and wet weather events.

To establish background water quality characteristics for the West River, the source data are analyzed with respect to BOD, TSS, fecal coliform, TN, and DO. The water quality characteristics are discussed in relation to dry and wet weather and in relation to spatial variations between sections of the West River upstream of and within New Haven.

Fecal Coliform

Table 3-15 presents select statistical parameters describing the variation of fecal coliform counts for dry and wet weather and for areas upstream and downstream of the New Haven/Woodbridge boundary.

TABLE 3-15
Fecal Coliform (MPN/100 mL)
West River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean (MPN/100mlL)	159	73
	Median (MPN/100mlL)	36	11
	No. Samples	33	43
Within New Haven	Mean (MPN/100mlL)	46000	1620
	Median (MPN/100mlL)	46000	700
	No. Samples	3	19

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991), and SCCRWA (1998)
There is no standard for the current classification; however, the water quality goal is 200 MPN/100 mL.

The plotted data are shown in Figure 3-13. There is considerable amount of scatter, and most fecal coliform measurements taken within New Haven exceed the state water quality classification of 200 MPN/100 mL for class B waters. Most of the measurements upstream of New Haven, regardless of weather, are below this standard. During wet weather, fecal coliform counts increase significantly. It appears as if there is considerable amount of bacteria entering the West River in New Haven itself. This is most likely from CSOs and during wet weather from stormwater discharges as well.

BOD

Table 3-16 presents select statistical parameters describing BOD concentrations with variations in weather and sampling locations. It shows the variation of BOD concentration both for dry and wet weather downstream of the New Haven/Woodbridge boundary. Figure 3-14 shows the data spread. According to the data, there is little difference between BOD concentrations during dry and wet weather conditions. More data sampling during wet weather would be necessary to validate this observation. No data was available on BOD upstream of New Haven. Concentrations of BOD are fairly low. It is generally believed that concentrations of BOD greater than 10-20 mg/L will lower the DO levels in rivers.

TABLE 3-16
Biochemical Oxygen Demand (mg/L)
West River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean (mg/L)	—	—
	Median (mg/L)	—	—
	No. Samples	0	0
Within City of New Haven	Mean (mg/L)	3.9	3.7
	Median (mg/L)	4.2	3.9
	No. Samples	3	19

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991) and SCCRWA (1998)

For comparison purposes, the WPAF's NPDES average monthly concentration limit is 30 mg/L (40 mg/L for wet weather).

There is no standard for the current classification; however, the water quality goal is 200 MPN/100 mL.

TSS

The data sets obtained by CH2M HILL had no suspended solids measurements. Turbidity was measured by the SCCRWA, but there is no clear correlation between turbidity and suspended solids.

Total Nitrogen

Table 3-17 presents select statistical parameters describing fecal coliform counts with variations in weather and sampling locations. It summarizes the total nitrogen concentrations in the West River. Figure 3-15 is a plot of the actual data. There is little difference between wet and dry weather. However, as seen from Table 3-17, nitrogen concentrations are significantly higher in New Haven than in Woodbridge. Possible reasons for this are CSO events (sewage has high nitrogen content) and stormwater runoff from fertilized parks and private lawns. Although there are no regulations controlling nitrogen concentrations, it is generally believed that concentration levels greater than 0.5-1.0 mg/L may cause adverse affects in river systems.

Figure 3-13
West River, Fecal Coliform

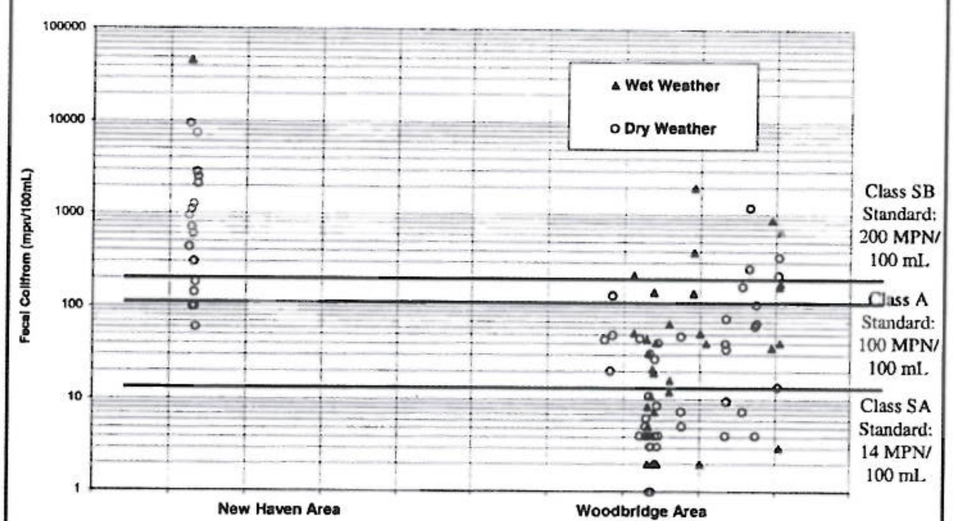
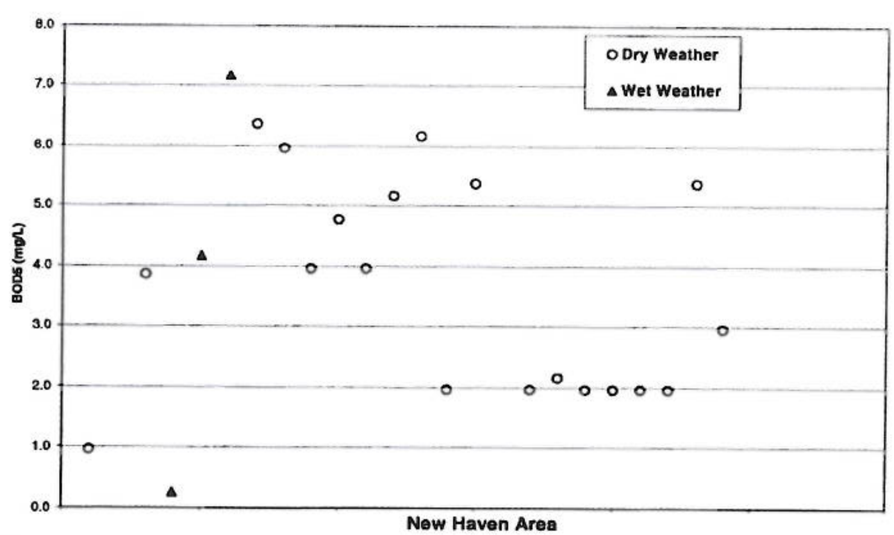


Figure 3-14
West River, BOD_5



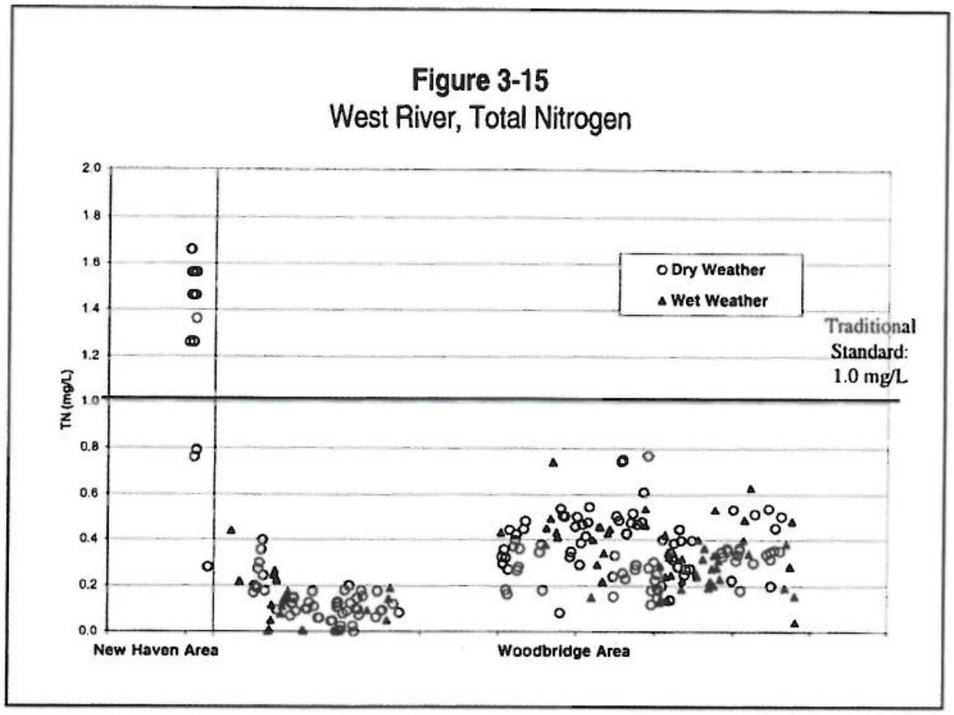


Figure 3-15
West River, Total Nitrogen
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
TN (mg/L)
New Haven Area
Woodbridge Area
Dry Weather
Wet Weather
Traditional Standard: 1.0 mg/L

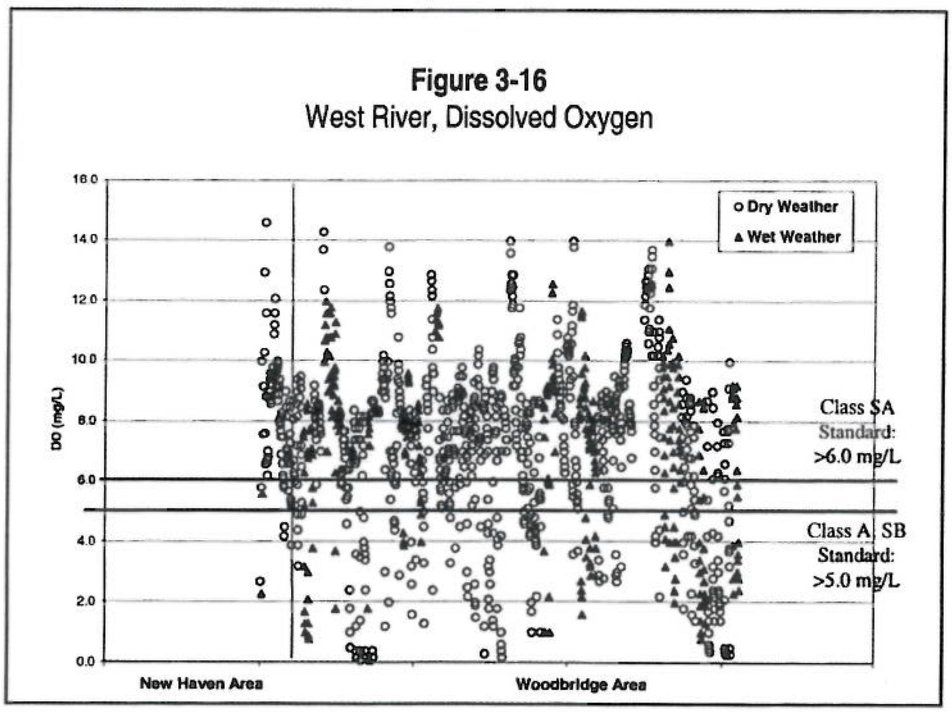


Figure 3-16
West River, Dissolved Oxygen
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
DO (mg/L)
New Haven Area
Woodbridge Area
Dry Weather
Wet Weather
Class SA Standard: >6.0 mg/L
Class A, SB Standard: >5.0 mg/L

Dissolved Oxygen

Table 3-18 presents select statistical parameters describing DO concentrations with variations in weather and sampling locations. Table 3-18 and Figure 3-16 show the DO concentrations in the West River. For the most part, state water quality standards of not less than 5 mg/L are met. The three data points shown for wet weather in New Haven were taken during 1974 and may not be representative of current

TABLE 3-17
Total Nitrogen (mg/L)
West River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean (mg/L)	0.3	0.4
	Median (mg/L)	0.3	0.3
	No. Samples	83	163
Within New Haven	Mean (mg/L)	—	1.5
	Median (mg/L)	—	1.6
	No. Samples	0	18

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991), and SCCRWA (1998)

TABLE 3-18
Dissolved Oxygen (mg/L)
West River

River Segment	Statistical Parameters	Wet Weather	Dry Weather
Upstream of New Haven	Mean (mg/L)	7.1	7.2
	Median (mg/L)	7.8	7.7
	No. Samples	349	967
Within City of New Haven	Mean (mg/L)	4.5	8.3
	Median (mg/L)	5.6	7.6
	No. Samples	3	17

Note: Data obtained from CTDEP (1974), Metcalf & Eddy (1991) and SCCRWA (1998)

Baseline River Concentrations

Concentration values used to represent the West River upstream of New Haven were chosen based on Figures 3-13 to 3-16 and Tables 3-15 to 3-18. The values of DO and TN are arithmetic averages of all measurements taken upstream of New Haven. The fecal coliform concentration is the median value of all measurements taken upstream of New Haven. There were no measurements of BOD upstream of New Haven, and TSS was not measured at all. BOD is estimated from data obtained for the Mill and Quinnipiac rivers. A baseline value for TSS of 15 mg/L was selected for the West River, similar to that for the Mill River. Table 3-19 shows the baseline pollutant concentrations in the West River as it enters the New Haven City boundary from North Haven.

TABLE 3-19
Baseline Pollutant Concentrations in the West River Upstream of New Haven

	TN (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	DO (mg/L)
Baseline Concentration	0.34	3.5	15	15	7.7
Standard/Goal	1.0[1]	n/a	n/a	100[2]	5.0[2]

[1] Traditional standard to prevent adverse impacts
[2] State standard for Class A waters is 100 total coliform / 100 mL; for Class SA waters, it is 14 fecal coliform / 100 mL; and for Class SB waters, it is 200 fecal coliform / 100 mL

New Haven Harbor

Water Quality Standards and Designated Uses

The state-delineated boundary between inner and outer harbor follows a line drawn between Lighthouse Point at the southeastern entrance to the harbor and a point on the western shore just south of Morse Park. Inner harbor water is currently designated as SD, and the outer harbor as SC. Class SD waters are considered unsuitable for most uses, due to reasons that are not readily correctable. Class SC indicates that the harbor cannot consistently meet contaminant levels that would allow harvesting of shellfish, with purification, and primary contact recreation.

Both the inner and outer harbor waters are designated for the future as SB, which would support shellfish harvesting, with purification, and primary contact recreation. Water quality classifications are indicated in Figure 3-1.

Water Quality

Existing water quality data were evaluated from four sources: USGS (1984-1995), Metcalf & Eddy (1991), CTDEP (1974), and CT DA/BA (1990-1996). The data sources are described below.

The USGS data (1984-1995) consist of 23 samples collected from October 1984 through September 1990 in the outer harbor. The USGS data was divided into wet and dry weather data, based on whether rainfall occurred on the sampling date.

Samples collected as part of Metcalf & Eddy (1991) were taken during three dry weather events: July 17–18, September 4–5, and October 17–18 at a number of locations in both the inner and outer harbor. The quality of data is exceptional and the scope comprehensive.

The CTDEP (1974) collected data on July 29 and 30, 1974 before and after a rain event, and, therefore, the data are considered to be wet and dry data. In 1974, the harbor was receiving effluent discharges from the three primary treatment plants: East Street Treatment Plant, East Shore Treatment Plant, and Boulevard Treatment Plant. There were also several raw sewage overflows that discharged continuously into the harbor. Since then, all wastewater flows have been redirected to the East Shore plant where secondary treatment has been implemented. Because of this, data collected by the CTDEP in 1974 may not be relevant to present conditions.

Data reviewed from the CT DA/BA (1990-1996) included samples collected at nine stations in the inner harbor from 1994 to 1996. Seven samples were collected at each station in 1996, and between 9 and 21 samples were collected over the previous 3-year period. The data were grouped into dry and wet weather conditions as defined by the Bureau's methodology.

Data from these sources are summarized in Tables 3-20 and 3-21. No TSS data was available. As shown in Table 3-20, fecal coliform counts have been reduced dramatically since 1974, and DO levels have significantly increased, indicating improved water quality. However, there is little difference between BOD and TN concentrations between the two time periods.

TABLE 3-20
Average Water Quality Characteristics in New Haven Harbor

Water Quality Parameter	Number of Samples	BOD (mg/L)	DO (mg/L)	Fecal Coliform (MPN/100 mL)	TN (mg/L)
1974	30	1.9	4.8	7700	1.2
1986 – 1996	136	3.5	9.6	100	0.64

Data Sources: CTDEP (1974), Metcalf & Eddy (1991), USGS (1984-1995), and CT DA/BA (1990-1996)

Table 3-21 shows the average water quality characteristics in New Haven Harbor for both wet and dry weather. The data indicates minor differences in BOD, DO, and FC concentrations and no change in TN concentrations during differing weather conditions.

For a more detailed spatial analysis of the harbor's water quality, refer to Metcalf & Eddy (1991) or CT DA/BA (1997). The results of these two reports indicate that the inner harbor region has lower DO concentrations and greater TN and fecal concentrations than the outer harbor. BOD concentrations do not vary significantly throughout the harbor. Results also indicate that the phase of the tide affects the concentration levels of fecal coliform. Low tide gives rise to higher fecal coliform concentrations.

Summary

Table 3-22 presents a comparison of pollutant concentrations in New Haven receiving waters. This data presents baseline concentration for the three rivers as determined by the analysis documented in this report plus data collected in New Haven Harbor to date. This data does not yet include impacts from CSO and stormwater discharges that will be determined in the following section of this report. However, as shown in the table, the Quinnipiac delivers the highest pollutant loading of TN and TSS to the harbor.

TABLE 3-21
Water Quality Data during Wet and Dry Weather
New Haven Harbor

River Segment	Statistical Parameters	Wet Weather	Dry Weather
BOD	Mean (mg/L)	3.2	3.1
	Median (mg/L)	2.5	2.4
	No. Samples	18	95
DO	Mean (mg/L)	7.6	6.6
	Median (mg/L)	7.5	7.0
	No. Samples	3	47
FC	Mean (MPN/100mL)	1400	1300
	Median (MPN/100mL)	39	60
	No. Samples	34	126
TN	Mean (mg/L)	0.6	0.8
	Median (mg/L)	0.6	0.8
	No. Samples	18	106

Data Sources: CTDEP (1974), Metcalf & Eddy (1991), USGS (1984-1995), and CT DA/BA (1990-1996)
For comparison purposes, the WPAF's NPDES average monthly concentration limit is 30 mg/L (40 mg/L for wet weather.

TABLE 3-22
Comparison of Pollutant Concentrations in New Haven Receiving Waters

	TN (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	DO (mg/L)
Quinnipiac River Baseline Concentration	5.7	3.5	56	1700	7.5
Mill River Baseline Concentration	0.7	3	15	130	8
West River Baseline Concentration	0.34	3.5	15	15	7.7
New Haven Harbor Data 1986-1996	0.64	3.5	--	100	9.6
Standard/Goal	1.0[1]	n/a	n/a	100[2]	5.0[2]

[1] Traditional maximum standard to prevent adverse impacts
[2] State standard for Class A waters (total coliform)

SECTION 4

Discharge Characterization

Previous sections of this report documented the overall status of water quality in each of New Haven's receiving waters. They identified existing and proposed recreational uses, commercial uses, sensitive areas, and water quality goals. In some areas of the City, and under certain conditions, the observed water quality fully supports these uses and goals. In others areas, or for other conditions, impairments related to CSOs, urban stormwater discharges, upstream pollutant sources, or other sources, prevent full attainment of these uses and goals.

To support the evaluation of impairments to receiving water quality and to identify water quality objectives which may be achieved through CSO controls, this section of the report documents the volumes, frequencies and durations of major discharges to New Haven's receiving waters. The specific sources of flow described in this section are:

- CSO discharges,
- urban stormwater discharges,
- watersheds upstream of New Haven, and
- the City's Water Pollution Abatement Facility.

The discharges from each source have been quantified for a planning scenario using the project's baseline conditions. The total discharges were calculated for four synthetic (design) storms:

- 1-month storm,
- 3-month storm,
- 1-year storm, and
- 2-year storm.

The hyetographs for each of these design events and the statistical analyses used to develop them are described in Appendix A. Results from these events are useful in evaluating the short-term impacts on water quality related to each discharge source. They are also useful in defining the general performance characteristics of the wastewater collection system and for the design of improvement projects.

In addition, another planning scenario – 1997 conditions – was evaluated for the CSO and WPAF sources, to provide a comparison between 1997 and baseline conditions.

Average annual flows were also studied for the project's baseline conditions. These flows are typically used to provide a more representative estimate of the long-term water quality characteristics of each water body and the benefits gained from improvement projects. These average annual flows (and the related pollutant loads described in Section 6) are based on one year of statistically average precipitation data. For this project, a long-term record (22 years of data) was used to identify a single year that best represents the long-term average. In selecting the year, the total annual precipitation, the number and sizes of storms, and seasonal trends were evaluated. The procedures used in this analysis are described in Appendix B.

This section briefly describes the sanitary system and stormwater models used in the analyses, then presents the results for the three scenarios:

- Design Storm Results (Baseline Conditions)
- Design Storm Results (1997 Conditions)
- Average Year Results (Baseline Conditions)

Sanitary System Model

The combined/sanitary sewer system model developed during Task 2 of the project was used to evaluate the sewer system's hydraulic characteristics under varying rainfall conditions. For more information about the model, see Technical Memorandum #3, *System Inventory and Model Results* (CH2M HILL December 1998).

Precipitation and tide data were input to the model so the hydrologic component of the model could be run for each design storm and the annual simulation. The results from the runs provided runoff hydrographs of wet-weather inflow to the sewers. Using these results, the hydraulic model could be run for each storm and the annual simulation, routing the flows through the sewer system. The resulting hydrographs were then evaluated to determine the volume, frequency, and duration of overflows (if any) at each regulator and the volumes and peak rates for the WPAF for each simulation.

To assess the impacts of the baseline sewer separation projects, both the calibration model (representing 1997 sewer conditions) and the baseline model were run for the design storms. The baseline model represents the conditions that will be achieved in a few years when the planned sewer separation projects have been completed. This section discusses the amount of separation in each watershed under baseline conditions and highlights the changes to the 1997 model made to develop the baseline model.

Sewer Separation

Under baseline conditions, the Quinnipiac River watershed has the greatest percentage of fully separated subcatchments. Hence, the river receives a greater percentage of its flow from stormwater than the other rivers. The Mill River watershed has the highest percentage of partially separated[1] subcatchments and no fully separated subcatchments. Therefore, less of the flow into the Mill River is from stormwater and possibly more is from CSOs than if it were fully separated (depending on the collection system's ability to accept wet-weather flow). In the West River watershed, the balance is about equal between combined, partially separated, and fully separated subcatchments. The New Haven Harbor watershed also has a substantial percentage of each subcatchment type, although it has more fully separated catchments than other types. The distribution of subcatchment types is shown in Table 4-1.

[1] Sewer separation refers to the construction of a new sewer so that sanitary flows can be conveyed to the WPAF without the significant addition of wet-weather runoff; storm sewers generally route wet-weather flows directly to receiving waters. Partial separation refers to a type of sewer separation in which some wet-weather connections to the sanitary sewer (for instance, roof leaders) still exist. In partial separation, the sanitary sewers convey dry-weather flow and some wet-weather flow, and the storm sewers convey the remaining wet-weather runoff.

TABLE 4-1
Distribution of Sewer Separation Within New Haven Under Baseline Conditions (acres and percent)

	Subcatchment Type				
	Combined	**Partially Separated**	**Separated**	**Non-sewered**	**TOTAL**
Quinnipiac River	334 (21%)	203 (13%)	971 (61%)	95 (6%)	1,603
Mill River	270 (30%)	636 (70%)	0 (0%)	8 (1%)	914
West River	1,026 (30%)	1,075 (32%)	1,145 (34%)	138 (4%)	3,384
Harbor	453 (21%)	558 (26%)	950 (45%)	148 (7%)	2,109
TOTAL	2,083	2,472	3,066	389	8,010

Active sewer separation projects that were included in the baseline conditions model include (see Figure 4-1):

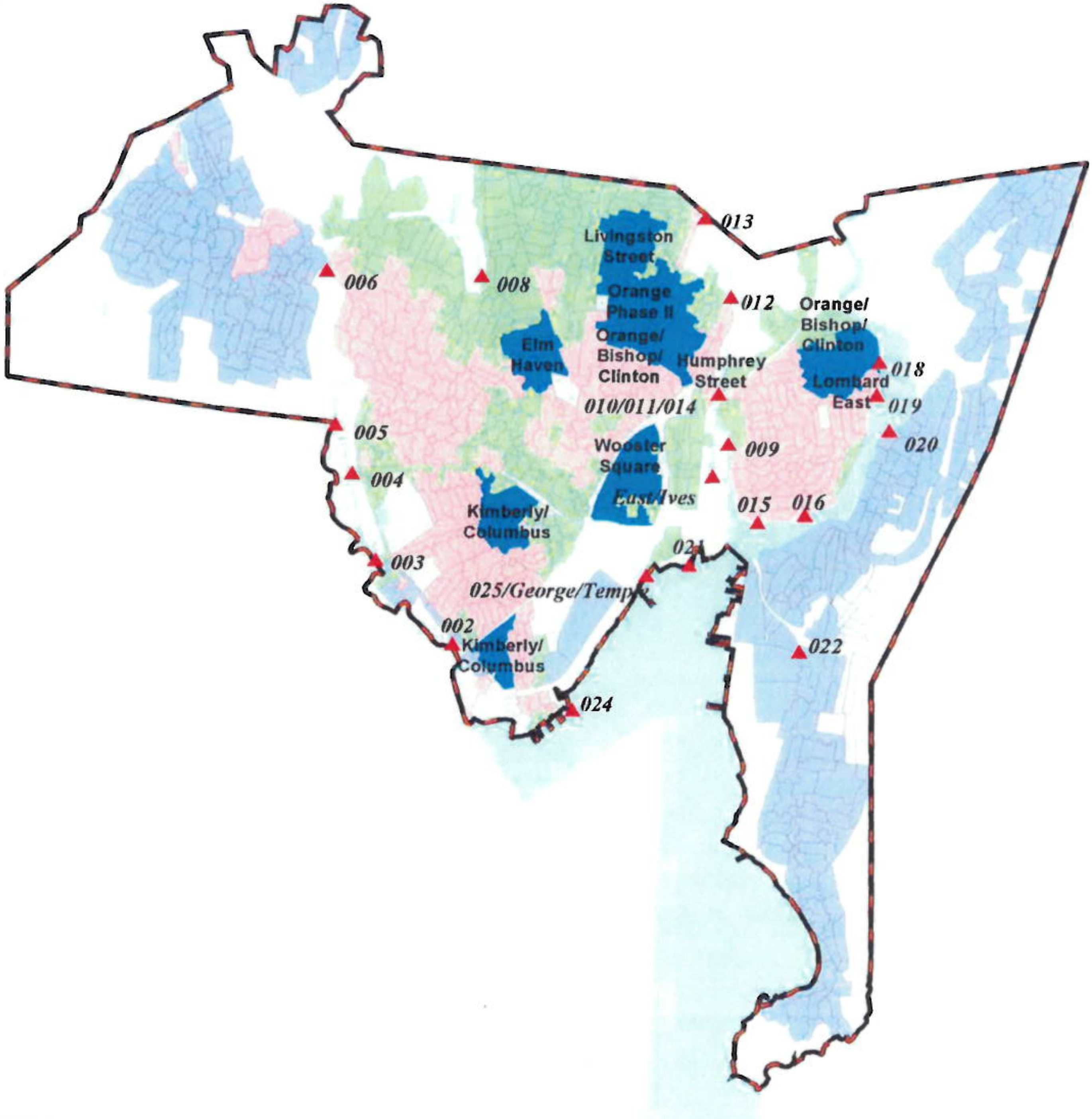
- Livingston Street, Phases I and II
- Orange Street Phase II
- Orange, Bishop, and Clinton
- Lombard Street East
- Wooster Square
- Humphrey Street
- Kimberly Avenue and Columbus
- Elm Haven

All catchments in these project areas, except those associated with the Elm Haven project, were classified as partially separated in the baseline model. Because the new storm sewers in Elm Haven will tie back to the combined sewer, these catchments continued to be classified as combined in the baseline model; however, the location where the stormwater enters the combined system was moved further downstream to represent the connection from the new storm sewer.

As part of the Humphrey Street sewer separation project, the existing weir will be demolished and a new weir will be built a few hundred feet west on Humphrey. Because exact specifications for the new weir were not available, characteristics such as crest elevation and crest type (broad vs. sharp) were assumed to be the same as those for the existing weir.

Other Changes

In the 1997 and verification models, the tide gate at CSO 016 (Poplar/River) was modeled as stuck partially open, representing the existing field condition. Such a condition allows tidal flows to enter the overflow pipe as well as limiting the exit of overflows. In the baseline model, the tide gate was restored and allowed to function properly.



New Haven City Boundary
CSO Outfall
Combined Catchment
Partially Separated Catchment
Separated Catchment
Non-Sewered Catchment
Sewer Separation Project

CH2MHILL

N
2000 0 2000 4000 Feet

Figure 4-1
Location of Active Sewer Separation Projects

New Haven Long Term CSO Control Plan

In response to field conditions, the WPCA modified three regulators in early 1998. The changes were included in the baseline model. The following list shows which regulators were impacted:

- CSO 004 (Boulevard/Legion Ave) – weir crests of all three weirs were raised to the same elevation of 6.9 ft USCGS (34" above the invert of the interceptor)
- CSO 009 (James St/Grand Ave) – the weir crest was raised six inches to 5.7 ft USCGS
- CSO 013 (East Rock Rd/Everit) – the weir crest was raised six inches to 22.2 ft USCGS

Both models include sediment in certain areas of the system, such as interceptors along Front Street in Fair Haven and along E. T. Grasso Boulevard. In many areas, velocities are sufficiently slow to cause the silt layer to build up quickly if the sewer were cleaned, so modeling the sediment represents a realistic condition.

Stormwater Model

The sanitary system model was used to calculate flows from CSOs and the WPAF in order to establish related potential pollutant loadings to the receiving waters. A second, simple model was developed to calculate pollutant loadings due to stormwater flows. In order to better compare local impacts, New Haven was divided into four watershed areas, one for each of the receiving waters (Figure 4-2): green (West River watershed), red (Mill River watershed), purple (New Haven Harbor watershed), and yellow (Quinnipiac River watershed). These watersheds were further broken down into sub-watersheds to provide spatial distribution of the stormwater inflows along the receiving waters. These detailed areas were defined based on subcatchment geometry according to the New Haven GIS database, stormwater piping details, and engineering judgment.

Three watershed areas carry runoff to New Haven Harbor, five run off into the West River, and two each correspond to the Mill and Quinnipiac Rivers. The largest of these areas is approximately 2 mi^2. Each watershed is comprised of small 10-acre subcatchments. Each subcatchment is characterized by a percent impervious and a sewer classification (i.e. combined, partially separated, fully separated). There were about 800 subcatchments delineated within the city. Figure 4-2 illustrates the demarcation of the watershed areas and each of the subcatchments.

Stormwater flows are calculated using the Simple Method (Schueler, 1987). The Simple Method is primarily intended for use on watersheds no greater than one square mile in area; larger watersheds may have a baseflow component that could significantly increase yearly runoff volumes. Although the watersheds are greater than 1 mi^2 in area, baseflows are typically not dominant for heavily urbanized areas, and research indicates that these groundwater baseflows do not usually deliver extra pollutant loads to receiving waters (Schueler, 1987). Runoff calculations were performed primarily at the subcatchment scale (8-10 acres).

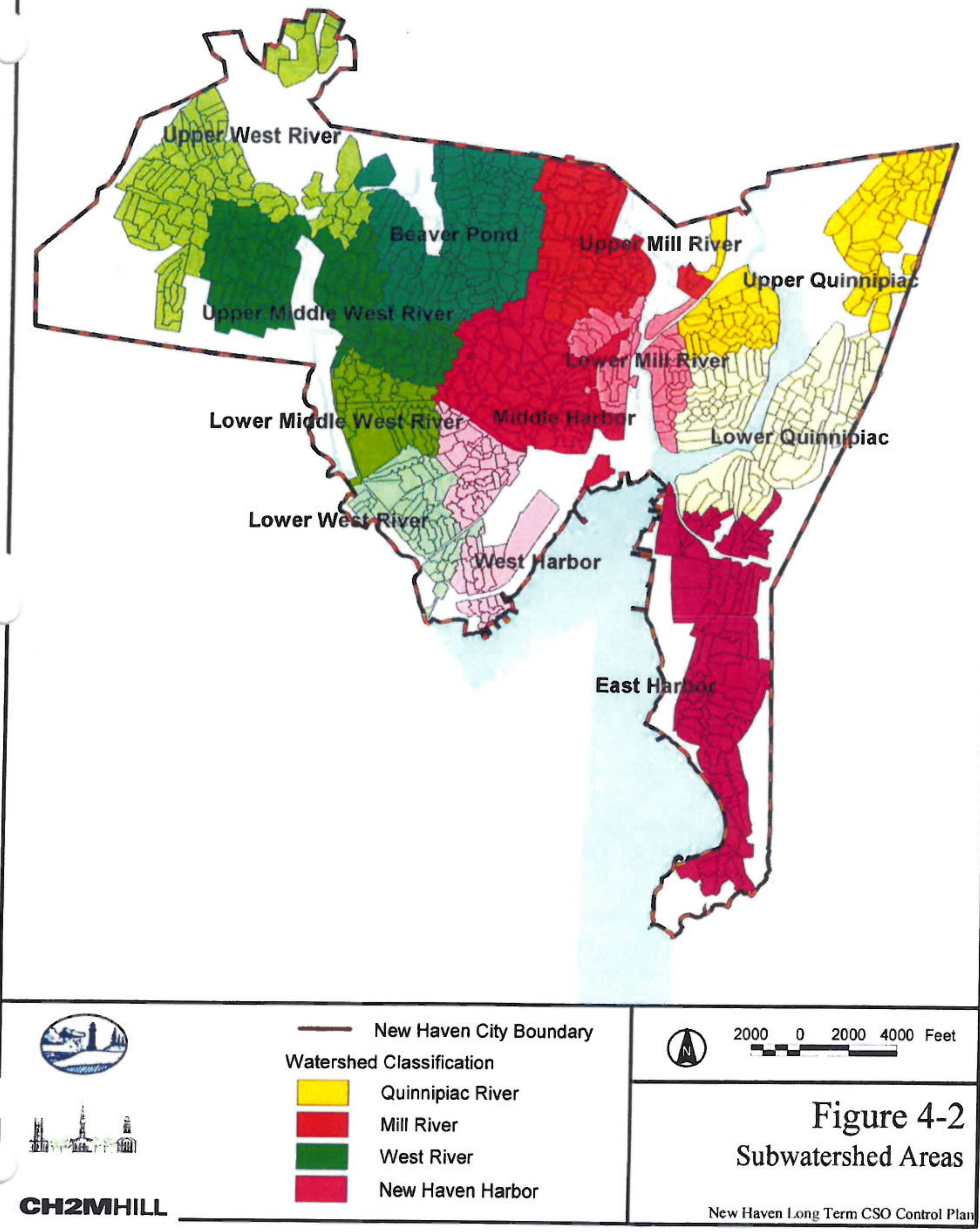


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Figure 4-2
Subwatershed Areas

New Haven Long Term CSO Control Plan

The Simple Method

The Simple Method was used to estimate the runoff volume with the following empirical equation:

$$Volume\ of\ Runoff = P \times P_j \times Rv \times A \qquad (A)$$

where:

* A is the area of the watershed.

* P is the depth of rainfall over the year. The average year's rainfall depth is 45.1 inches (see Appendix B).

* P_j is a correction factor used to account for the fraction of annual rainfall that does not produce any measurable runoff. Schueler's recommended value of 0.9 was adopted.

* R_v is a runoff coefficient that is linearly related to the imperviousness of the watershed area. Schueler recommends the use of the following relationship between runoff and imperviousness:

$$R_v = 0.05 + 0.009 \times I$$

where I is the percent impervious of the site.

Impervious cover throughout New Haven is shown in Figure 4-3. The imperviousness for each sub-watershed was calculated using an areally-weighted average.

To account for the various types of collection systems in New Haven, an additional factor was added to Equation (A). In the combined/sanitary sewer model, it is assumed that a certain amount of rainfall makes its way into the sanitary sewer system. The amount of runoff that enters the sanitary system varies depending on the sewer classification of the subcatchment (Figure 4-4). It was assumed that the volume of rainfall that did *not* make its way into the sanitary sewer is potentially available for runoff as in equation (*A*). In order to indicate that only a portion of runoff enters the sanitary system, an adjustment factor is applied to the depth of rainfall by sewer classification (this factor is shown in Table 4-2). The remaining portion of the runoff is assumed to be captured by the combined/sanitary sewer system.

TABLE 4-2
Adjustment Factors Applied to the Volume of Rainfall to Account for Flow Not Captured by the Combined/Sanitary System

Sewer Classification	Combined Sewers	Partially Separated Sewers	Separated Sewers	Non-Sewered
Adjustment Factor	0.25	0.75	0.90	1.00

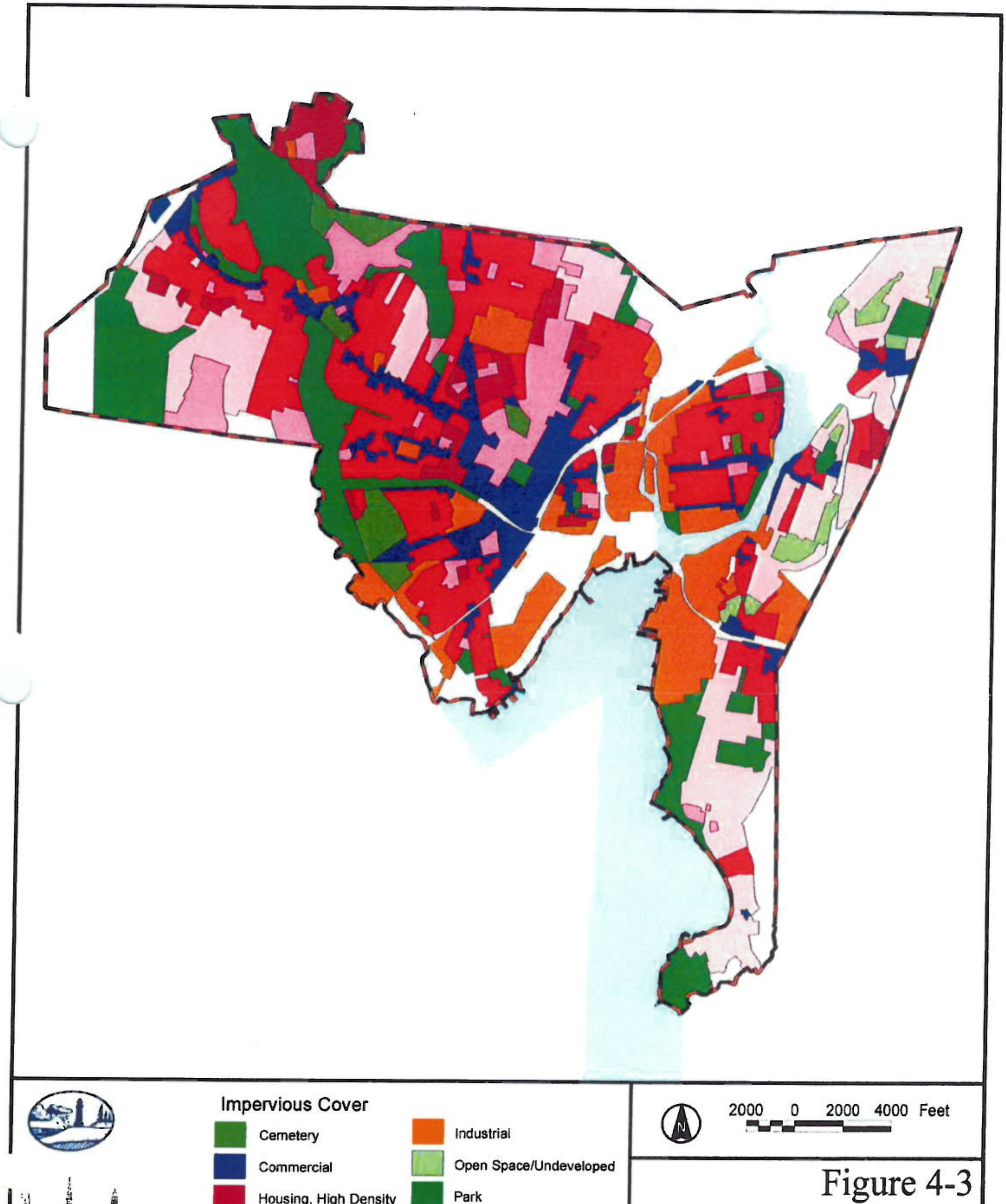

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Figure 4-3
Impervious Cover

New Haven Long Term CSO Control Plan

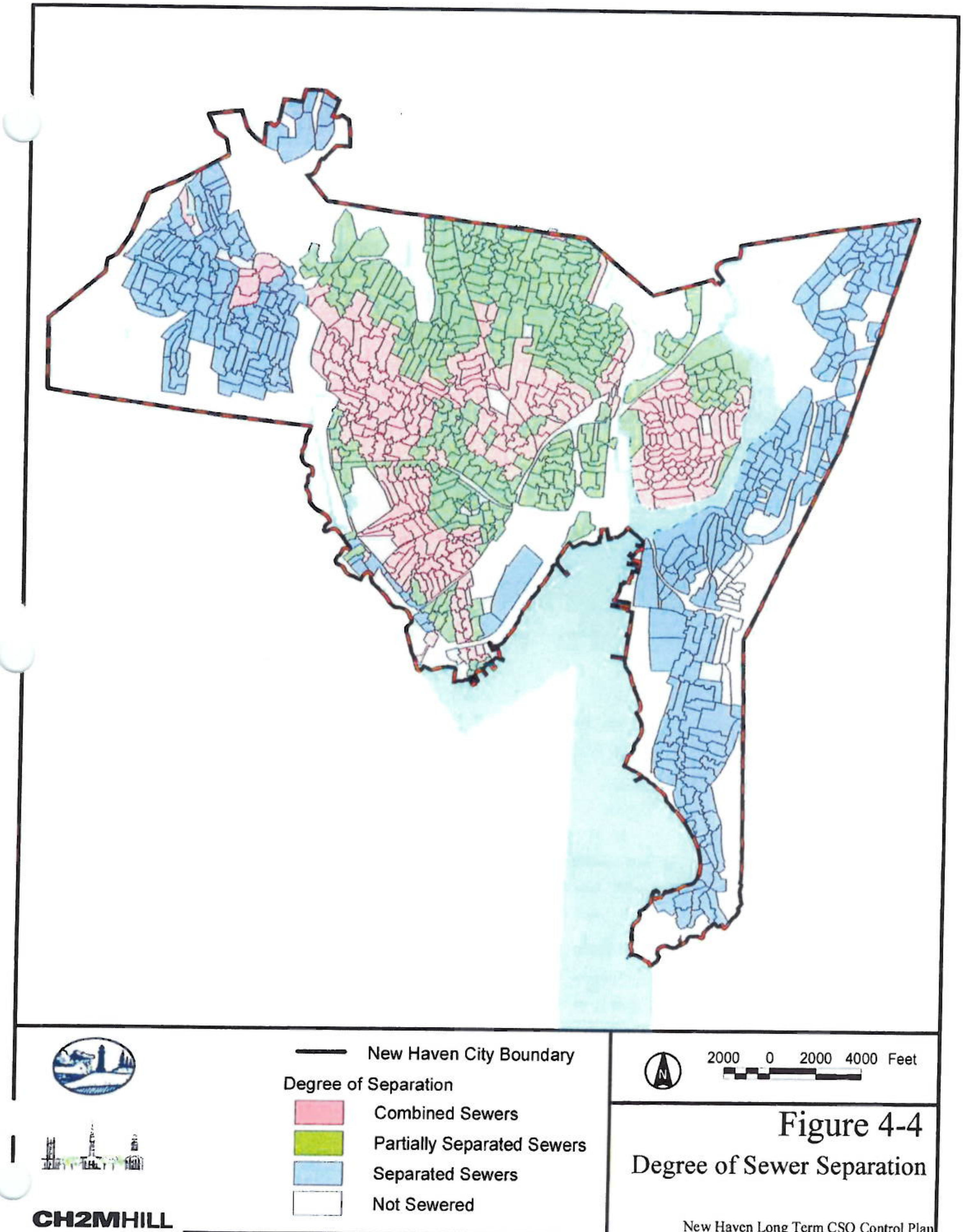


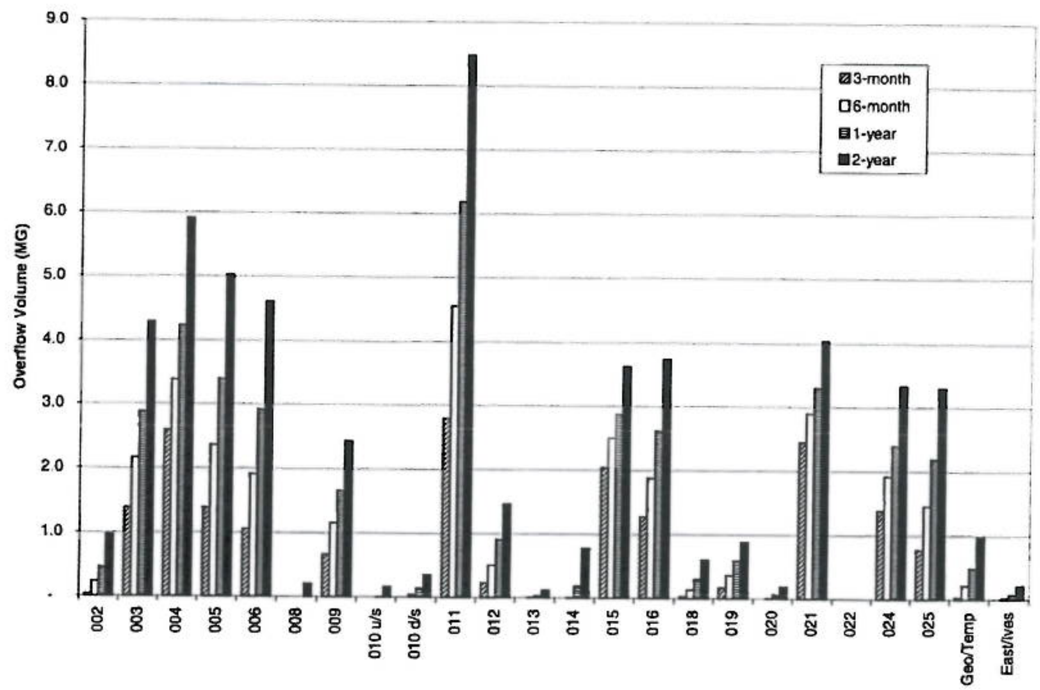
Figure 4-4
Degree of Sewer Separation

Design Storm Results: Baseline Conditions

CSOs

Table 4-3 shows the CSO volumes associated with each regulator during the design storm simulations, organized from upstream to downstream for each receiving water. The largest overflows occurred at 011. Some of the sites, including 008, 010 upstream, and 013, have overflows for only larger storms like the 2-year storm. Figure 4-5 displays the CSO volumes for the four design storms at all sites, for comparison of the relative magnitude of overflow at each site. Compared to other cities in the northeast, the CSO volumes are relatively small.

FIGURE 4-5
CSO Volumes for Design Storms (Baseline Model)



Stormwater

Using the total rainfall volume for each design storm (1.11" for 3-month storm and 2.05" for 2-year storm), the volumes of flows were calculated using equation (*A*) with adjustments from Table 4-2. This calculation was performed for each subcatchment within each of the watershed areas. For areas in which there was no subcatchment delineated, it was assumed that the area was non-sewered with an imperviousness of 10 percent[2]. These areas are typically along the banks of the river and include areas such as East Rock and West Rock Parks. The resulting volumes of runoff are shown in Table 4-4 for the 3-month and 2-year design storms.

[2] It was assumed this land was primarily parklands or open space. The value of 10% impervious falls within the range of 5%-30% recommended in Linsley et al. (1992) for parks.

TABLE 4-3
CSO Volumes for Design Storms with Baseline Model (MG)

NPDES #	Location	3-month	6-month	1-year	2-year
	WEST RIVER				
006	Whalley Ave./Fitch St.	1.1	1.9	2.9	4.6
005	Boulevard/Derby Ave.	1.4	2.4	3.4	5.0
004	Boulevard/Legion Ave.	2.6	3.4	4.2	5.9
003	Boulevard/Orange Ave.	1.4	2.2	2.9	4.3
002	Boulevard/Lamberton St.	—	0.2	0.5	1.0
	WEST RIVER TOTAL	**6.5**	**10.1**	**13.9**	**20.8**
	BEAVER PONDS				
008	Munson St./Orchard St.	—	—	—	0.2
	BEAVER PONDS TOTAL	**—**	**—**	**—**	**0.2**
	MILL RIVER				
013	East Rock Rd.	—	—	—	0.1
012	Mitchell Dr. / Nicoll St.	0.2	0.5	0.9	1.5
010	East St./I-91 (upstream weir)[1]	—	—	—	0.2
010	East St./I-91 (downstream weir)[2]	—	—	0.1	0.3
011	Humphrey St. / State St. (new weir)[1]	2.8	4.6	6.2	8.5
014	Trumbull St. / Orange St.[1]	—	—	0.2	0.8
009	James St./Grand Ave.	0.7	1.2	1.7	2.4
n/a	East St. / Ives Place	—	—	0.1	0.2
	MILL RIVER TOTAL	**3.7**	**6.3**	**9.2**	**14.0**
	QUINNIPIAC RIVER				
018	N. Front St. / Lombard St.	—	0.1	0.3	0.6
019	N. Front St. / Pine St.	0.2	0.4	0.6	0.9
020	Quinnipiac Ave. / Clifton St.	—	—	0.1	0.2
016	Poplar St. / River St.	1.3	1.9	2.6	3.7
015	James St. Siphon	2.0	2.5	2.9	3.6
	QUINNIPIAC RIVER TOTAL	**3.5**	**4.9**	**6.5**	**9.0**
	NEW HAVEN HARBOR				
021	East St. Pump Station	2.4	2.9	3.3	4.0
025	Union Pump Station[3]	0.8	1.5	2.2	3.3
n/a	George St. / Temple St.[3]	—	0.2	0.5	1.0
022	Allen Place[4]	*	*	*	*
024	Boulevard Pump Station	1.4	1.9	2.4	3.3
	NEW HAVEN HARBOR TOTAL	**4.6**	**6.5**	**8.4**	**11.6**
	GRAND TOTAL	**18.3**	**27.8**	**38.0**	**55.6**

Note: Volumes are rounded to nearest 0.1 MG. A lack of an overflow is shown as a dash.
[1] Regulators 010 (upstream), 011, and 014 share a common outfall.
[2] Regulator 010 (downstream) is 8 feet downstream of the upstream weir and has its own outfall.
[3] Regulators 025 and George/Temple share a common outfall.
[4] At 022, there is a large amount of highway drainage in a storm sewer and a small sanitary connection. Because the model included the combined and sanitary pipes but not the storm pipes, this CSO is not triggered in the model. The short-term control plan will examine whether the sanitary connection can be removed from the storm pipe, thereby eliminating the CSO.

TABLE 4-4
Stormwater Discharges for the 6-Hour-Duration Design Storms, Baseline Conditions (MG)

Design Storm	Quinnipiac River	Mill River	West River	New Haven Harbor
watershed area	2240 acres	1160 acres	4930 acres	3270 acres
3-month	17.0	8.5	34.4[1]	26.6
2-year	31.3	15.7	63.3[1]	49.1

[1] The runoff volumes to the Beaver Ponds (1080 acres) were 9.0 MG (3-month storm) and 16.5 MG (2-year storm). The Beaver Ponds runoff volumes are included in the numbers reported for the West River.

East Shore WPAF

Table 4-5 shows the treated flow volumes and peak influent rates to the WPAF for each of the design storms. The volume is based on the flows that exceeded the typical peak dry-weather flow rate (40 mgd) as a result of the storms. The percentage increase in volume and flow rate for each of the design storms compared to the 3-month storm is also given, to provide a comparison between the different storms. As the return period of the design storms increase, so do the volumes of flow treated and the peak flow rates, indicating that at least part of the larger wet-weather flows is being captured and treated.

TABLE 4-5
Flow Through East Shore WPAF During Design Storms, Baseline Conditions

Parameter	3-Month Storm	6-Month Storm	1-Year Storm	2-Year Storm
Volume Treated (MG)[1]	23.0	25.4	25.2	28.9
Peak Influent Rate (mgd)[2]	86.9	95.8	98.7	106.4
Comparison to 3-Month Storm Results				
Volume Treated		+10%	+10%	+26%
Peak Influent Rate		+10%	+14%	+22%

[1] The volume treated by the WPAF when flows exceeded the typical dry-weather flow rate (40 mgd) as a result of the storms.

[2] Average dry-weather flow is about 30 mgd.

Receiving Water Flows

For the design storms, flows in the rivers were based on the median flow rate in the average year. Volumes were then calculated for a six-hour period using the median flow rate. For the harbor, the volume was based on the sum of the inflows from the rivers, stormwater, CSOs, and WPAF.

Summary

The following table summarizes the volumes entering the receiving waters from each of the flow sources for the design storms under baseline conditions.

TABLE 4-6
Flow Volume Summary for the Design Storms, Baseline Conditions (MG)

Flow Source	Quinnipiac River	Mill River	West River	New Haven Harbor
3-MONTH DESIGN STORM				
River Inflow[1]	23.5	7.1	2.9	109.7
CSO	3.5	3.7	6.5	4.6
Stormwater	17.0	8.5	34.4	26.6
East Shore WPAF[2]	—	—	—	23.0
Total (3-month)	**44.0**	**19.3**	**43.8**	**163.9**
2-YEAR DESIGN STORM				
River Inflow[1]	23.5	7.1	2.9	186.4
CSO	9.0	14.0	21.0	11.6
Stormwater	31.3	15.7	63.3	49.1
East Shore WPAF[2]	—	—	—	28.9
Total (2-year)	**63.8**	**36.8**	**87.2**	**276.0**

[1] For the rivers, the volume is based on the river flows during the average year. The volume given in this table is from the median flow rate for a six-hour period. For the harbor, the volume is based on the sum of the inflow to all the rivers (background river inflow, CSO flow, stormwater flow).

[2] The volume given for the WPAF is based on the flows from the WPAF that exceed the typical peak dry-weather flow (40 mgd) as a result of the storm. For these design storms, that period was approximately 8 hours in duration.

Design Storm Results: 1997 Conditions

CSOs

Table 4-7 lists the CSO volumes for the model runs with 1997 sewer system conditions, organized from upstream to downstream for each receiving water. Recall that differences between the baseline and 1997 conditions models included sewer separation; weir elevations at 004, 009, and 013; and the tide gate at 016. Figures 4-6 to 4-9 show comparisons between the overflow volumes for the 1997 and baseline conditions for the 3-month, 6-month, 1-year, and 2-year design storms, respectively. The baseline model indicates smaller CSO volumes than the 1997 model for many of the sites, due to the effects of sewer separation.[3] However, a larger overflow was estimated at CSO 016 in the 1997 model because of the change in the way the tide gate was modeled. In the 1997 model, the tide gate was modeled as defective (stuck partially open), which decreased the amount of overflow that could pass through the gate. In the baseline model, the tide gate was fully functional, allowing more overflow to pass through. The figures show how regulators 015

[3] Note that because roof leaders are not disconnected from the combined sewers when sewer separation is constructed, the combined sewers still receive inflow during storms. These catchments are modeled as "partially separated." Refer to Technical Memorandum 3, *System Inventory and Model Results* (CH2M HILL December 1998) for more information.

TABLE 4-7
CSO Volumes for Design Storms with 1997 Conditions Model (MG)

NPDES #	Location	3-month	6-month	1-year	2-year
	WEST RIVER				
006	Whalley Ave./Fitch St.	1.1	1.9	2.9	4.6
005	Boulevard/Derby Ave.	1.4	2.4	3.4	5.0
004	Boulevard/Legion Ave.	2.7	3.6	4.4	6.1
003	Boulevard/Orange Ave.	1.4	2.2	2.9	4.3
002	Boulevard/Lamberton St.	0.1	0.3	0.5	1.1
	WEST RIVER TOTAL	**6.7**	**10.4**	**14.1**	**21.1**
	BEAVER PONDS				
008	Munson St./Orchard St.	—	—	—	0.2
	BEAVER PONDS TOTAL	**—**	**—**	**—**	**0.2**
	MILL RIVER				
013	East Rock Rd.	0.1	0.1	0.3	0.8
012	Mitchell Dr. / Nicoll St.	0.7	1.3	1.9	2.7
010	East St./I-91 (upstream weir)[1]	—	0.1	0.3	0.7
010	East St./I-91 (downstream weir)[2]	—	0.2	0.4	0.7
011	Humphrey St. / State St.[1]	4.0	5.9	7.4	9.9
014	Trumbull St. / Orange St.[1]	—	—	0.3	0.9
009	James St./Grand Ave.	0.9	1.5	2.0	2.8
n/a	East St. / Ives Place	—	0.2	0.4	0.7
	MILL RIVER TOTAL	**5.7**	**9.3**	**13.0**	**19.2**
	QUINNIPIAC RIVER				
018	N. Front St. / Lombard St.	0.3	0.7	1.1	1.7
019	N. Front St. / Pine St.	0.4	0.7	1.0	1.5
020	Quinnipiac Ave. / Clifton St.	—	—	0.1	0.2
016	Poplar St. / River St.	0.9	1.1	1.3	1.7
015	James St. Siphon	2.3	3.0	3.5	4.6
	QUINNIPIAC RIVER TOTAL	**3.9**	**5.5**	**7.0**	**9.7**
	NEW HAVEN HARBOR				
021	East St. Pump Station	3.1	3.7	4.2	5.4
025	Union Pump Station[3]	1.3	2.2	3.1	4.2
n/a	George St. / Temple St.[3]	—	0.2	0.5	1.0
022	Allen Place[4]	*	*	*	*
024	Boulevard Pump Station	1.5	2.0	2.5	3.5
	NEW HAVEN HARBOR TOTAL	**5.9**	**8.1**	**10.3**	**14.1**
	GRAND TOTAL	**22.2**	**33.3**	**44.4**	**64.3**

Note: Volumes are rounded to nearest 0.1 MG. A lack of an overflow is shown as a dash.
[1] Regulators 010 (upstream), 011, and 014 share a common outfall.
[2] Regulator 010 (downstream) is 8 feet downstream of the upstream weir and has its own outfall.
[3] Regulators 025 and George/Temple share a common outfall.
[4] At 022, there is a large amount of highway drainage in a storm sewer and a small sanitary connection. Because the model included the combined and sanitary pipes but not the storm pipes, this CSO is not triggered in the model. The short-term control plan will examine whether the sanitary connection can be removed from the storm pipe, thereby eliminating the CSO.

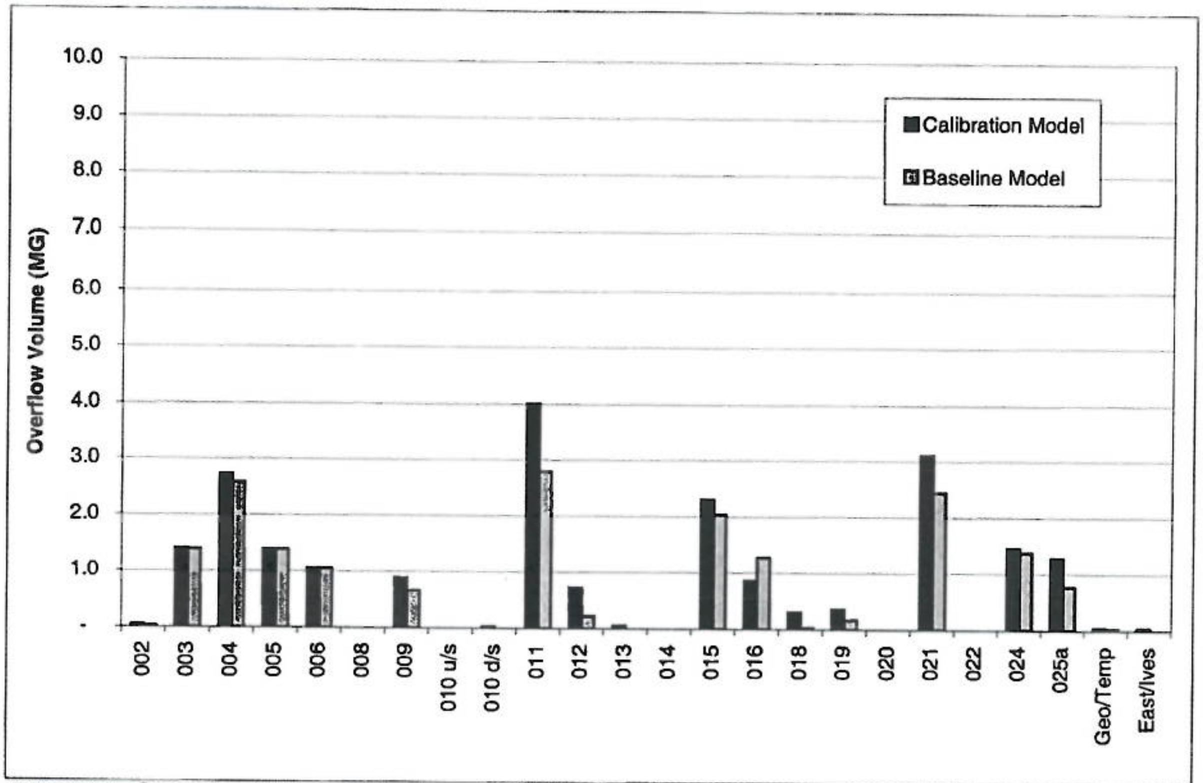


FIGURE 4-6. *Comparison between CSO volumes for 1997 and baseline conditions (3-month storm)*

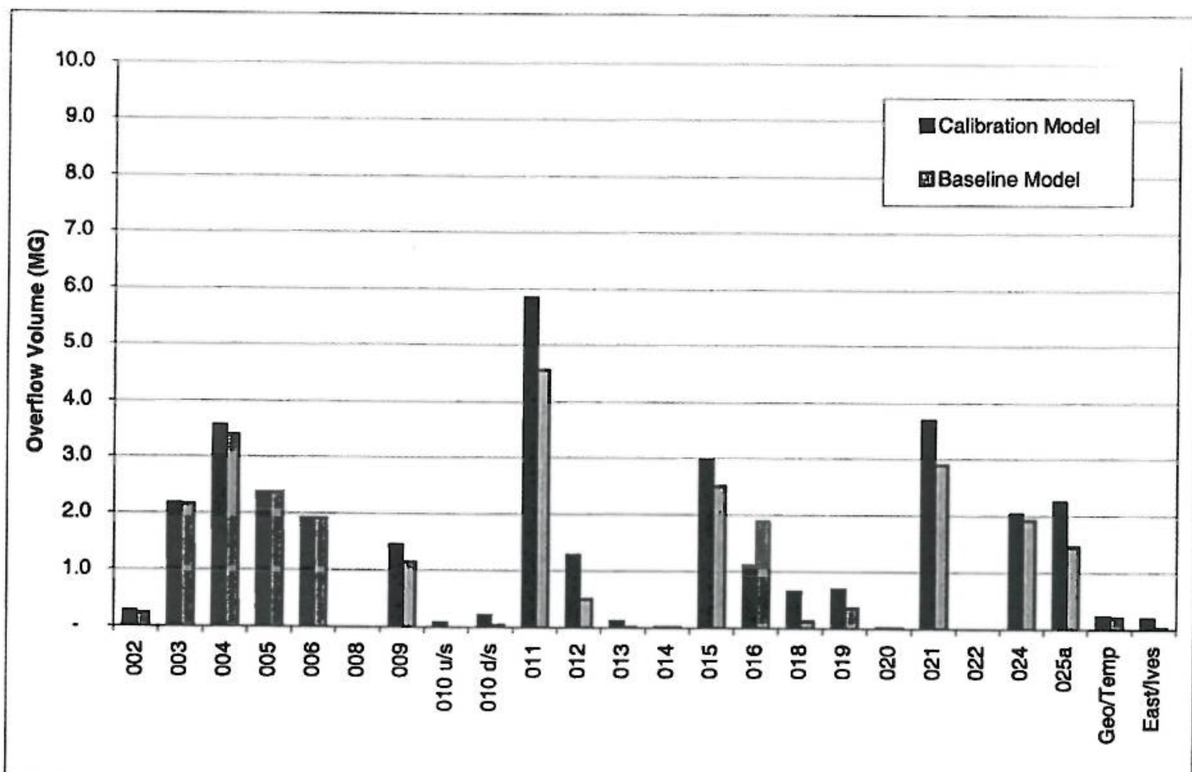


FIGURE 4-7. *Comparison between CSO volumes for 1997 and baseline conditions (6-month storm)*

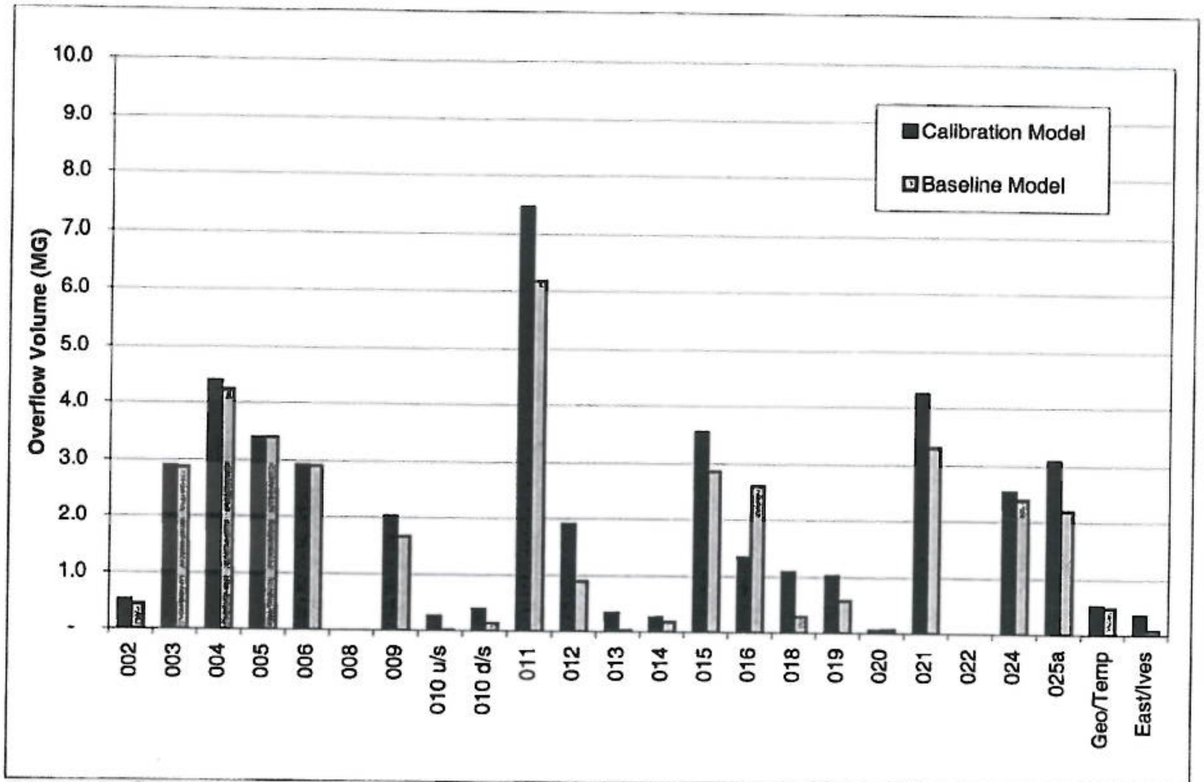


FIGURE 4-8. *Comparison between CSO volumes for 1997 and baseline conditions (1-year storm)*

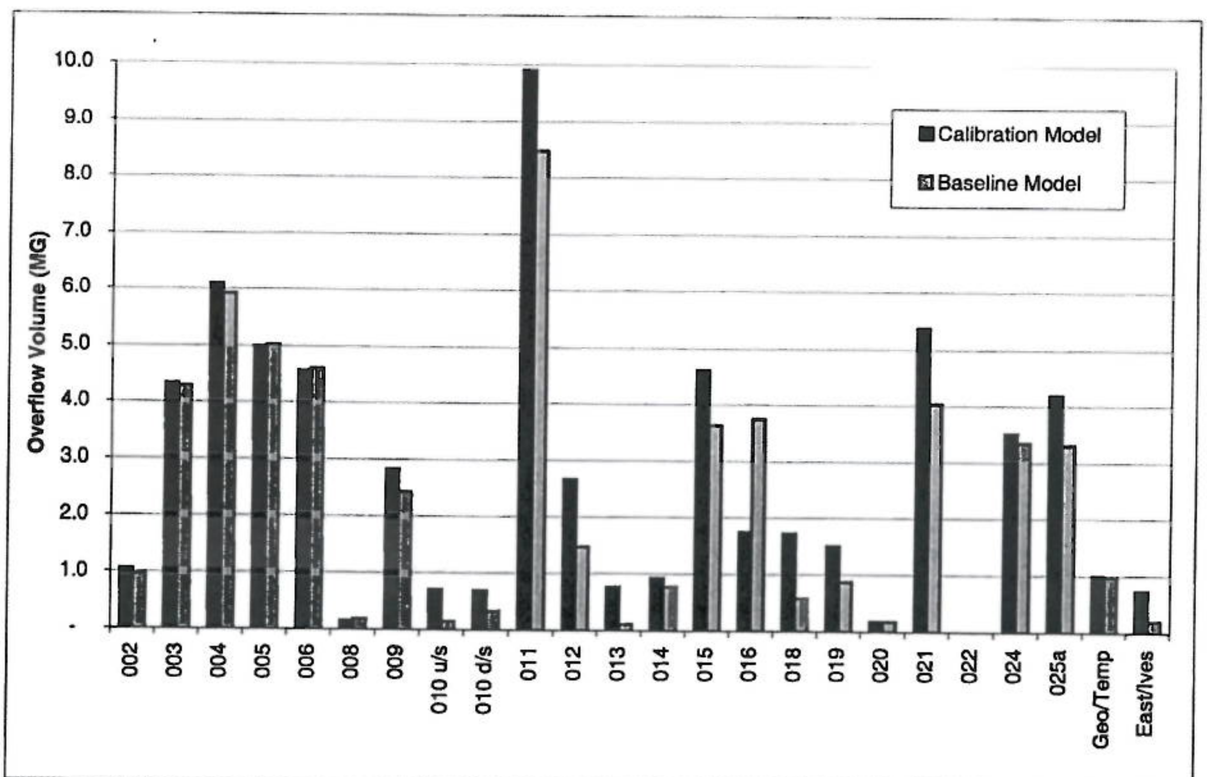


FIGURE 4-9. *Comparison between CSO volumes for 1997 and baseline conditions (2-year storm)*

and 016 work together because of their proximity. When larger overflows are possible at 016 (the upstream site), smaller overflows result at 015. Overflows at the two sites tend to balance when the tide gate at 016 is modeled as operating correctly.

Table 4-8 shows the percentage reduction and elimination of CSOs as a result of the separation projects and other changes that are represented by baseline conditions. As can be seen, CSO 013 was eliminated for all but the 2-year storm in the model simulations. Other CSOs also had substantial reductions in CSO volume.

TABLE 4-8
Effectiveness of Sewer System Improvement Projects (Comparison of 1997 and Baseline Model Results)

CSO #	Percent of Service Area Separated	Sewer Separation Project or Other Sewer System Improvement	3-Month	6-Month	1-Year	2-Year
004	n/a	Raising of weirs	-4%	-6%	-5%	-3%
009	n/a	Raising of weir	-22%	-20%	-15%	-14%
011	29	Humphrey St	-30%	-22%	-16%	-14%
012	93	Livingston St; Orange St Phase II; Orange, Bishop, Clinton	-71%	-62%	-53%	-44%
013	92	Livingston St; raising of weir	eliminated	eliminated	eliminated	-88%
018	96	Lombard East; Orange, Bishop, Clinton	eliminated	-86%	-73%	-65%
024	58	Kimberly and Columbus	-7%	-5%	-4%	-6%

Notes: a (-) indicates a reduction in overflow volume from 1997 conditions to baseline conditions

East Shore WPAF

Table 4-9 shows the treated flow volumes and peak influent rates to the WPAF for each of the design storms from the 1997 conditions model. The percentage increase in volume and flow rate for each of the design storms compared to the same values from the baseline model simulations is also given. As would be expected, the volumes and rates are slightly higher than their counterparts from the baseline simulations, resulting from the capture of more wet-weather flow by the combined sewers in 1997. Baseline conditions included separation projects that helped remove some of the wet-weather flow from combined sewers. It can be seen from the table, however, that the increases are quite small.

Average Year Results: Baseline Conditions

CSOs

Table 4-10 shows the volume, frequency, and duration of CSOs during the average rainfall year for each receiving water. The results are presented in order from upstream to downstream. It also indicates the average volume per event and average duration per event. Figure 4-10 shows the same information in a graph, sorted by CSO volume, that makes it easy to compare individual sites. The figure shows that some sites, such as 015, 004, 024, and 011, have high frequencies and volumes of CSO, leading to a higher average volume per event. Sites 005, 016, 003, 006, 009, and 012 stand out as sites where the frequencies are high but the volumes are not. Such sites may be improved significantly using short-term, inexpensive controls such as raising weirs. Site 004 has a notably higher average duration per event than any other site. Most of the sites have low average volumes per event.

TABLE 4-9
Flow Through East Shore WPAF During Design Storms, 1997 Conditions

Parameter	3-Month Storm	6-Month Storm	1-Year Storm	2-Year Storm
Volume Treated (MG)[1]	23.6	25.6	26.2	30.1
Peak Influent Rate (mgd)	87.5	95.8	99.5	106.9
Comparison to Results for Baseline Conditions Model				
Volume Treated	+3%	+1%	+4%	+4%
Peak Influent Rate	+1%	no change	+1%	+1%

[1] The volume treated by the WPAF when flows exceeded the typical dry-weather flow rate (40 mgd) as a result of the storms.
[2] Average dry-weather flow is about 30 mgd.

Stormwater

Since the annual simulation provides gross estimates for CSO and stormwater discharge volumes, flow values were combined by watershed area, instead of by sub-watershed. Table 4-11 presents stormwater runoff results for the annual simulation. As seen from the table, the West River receives the most stormwater runoff of the four watersheds, while the Mill River has the least. It is important to remember that these numbers do not represent the total amount of runoff into the rivers, but rather the total amount of runoff from New Haven. A significant amount of runoff may enter the rivers from neighboring communities. Stormwater pollutant loads from those communities are not known.

East Shore WPAF

At the WPAF, all flows up to approximately 100 mgd receive screening, grit removal, and primary treatment. Flows up to 60 mgd receive secondary treatment; flows in excess of 60 mgd are blended with secondary treatment effluent, and all effluent is then disinfected prior to discharge. Table 4-12 shows the volume of flow treated by the WPAF during the average year simulation. It also indicates the peak influent flow rate to the WPAF. During the annual simulation, the secondary capacity of 60 mgd was exceeded 48 times.

TABLE 4-10
CSO Statistics for Average Year Simulation

NPDES #	Location	Volume (MG)	Frequency (#)	Duration (hours)	Average Volume per Event (MG)	Average Duration per Event (hr)
		WEST RIVER				
006	Whalley/Fitch	7.9	19	46	0.4	2
005	Blvd/Derby	17.1	44	246	0.4	6
004	Blvd/Legion	38.4	39	578	1.0	15
003	Blvd/Orange	15.4	26	79	0.6	3
002	Blvd/Lamberton	0.7	7	9	0.1	1
	WEST RIVER TOTAL	**79.5**	**135**	**958**	**n/a**	**n/a**
		BEAVER PONDS				
008	Munson/Orchard	0.02	3	1	0.01	0.4
	BEAVER PONDS TOTAL	**0.02**	**3**	**1**	**n/a**	**n/a**
		MILL RIVER				
013	East Rock Rd	0.02	1	2	0.02	2
012	Mitchell/Nicoll	1.7	14	33	0.1	2
010	East/I-91 (upstream)[1]	0.01	1	0.02	0.01	0.02
010	East/I-91 (downstream)[2]	0.2	2	3	0.1	1
011	Humphrey/I-91[1]	28.1	25	81	1.1	3
014	Trumbull/Orange[1]	0.1	1	1	0.1	1
009	James/Grand	6.5	28	78	0.2	3
n/a	East/Ives	0.1	4	6	0.03	1
	MILL RIVER TOTAL	**36.7**	**76**	**203**	**n/a**	**n/a**
		QUINNIPIAC RIVER				
018	N. Front/Lombard	0.5	5	10	0.1	2
019	N. Front/Pine	1.5	8	21	0.2	3
020	Quinnipiac/Clifton	0.1	1	1	0.1	1
016	Poplar/River[3]	16.3	39	206	0.4	5
015	James St Siphon	43.9	45	223	1.0	5
	QUINNIPIAC RIVER TOTAL	**62.3**	**98**	**461**	**n/a**	**n/a**
		NEW HAVEN HARBOR				
021	East St PS	51.2	26	115	2.0	4
025	Union PS[4,5]	7.1	7	17	1.0	2
n/a	George/Temple[4]	0.8	5	7	0.2	1
022	Allen Place[6]	n/a	n/a	n/a	n/a	n/a
024	Blvd PS	32.3	26	109	1.2	4
	NEW HAVEN HARBOR TOTAL	**59.0**	**38**	**139**	**n/a**	**n/a**
	GRAND TOTAL	**237.5**	**350**	**1,763**	**n/a**	**n/a**

[1] Regulators 010 (upstream), 011, and 014 share a common outfall.
[2] Regulator 010 (downstream) is 8 feet downstream of the upstream weir and has its own outfall.
[3] There were 5 occurrences of inflow due to high tides at regulator 016, with a total (annual) volume of 0.05 MG.
[4] Regulators 025 and George/Temple share a common outfall.
[5] There were 120 occurrences of inflow due to high tides at regulator 025, with a total (annual) volume of 81 MG.
[6] This site is essentially a stormwater pipe with a small sanitary connection that forces it to be classified as combined. Because the stormwater pipes were not modeled, the model indicates no overflows, although they occur in the field. Improvements necessary to eliminate this overflow will be investigated in the project's Short-Term Control Plan.

Figure 4-10
Characteristics of CSOs in the Average Year

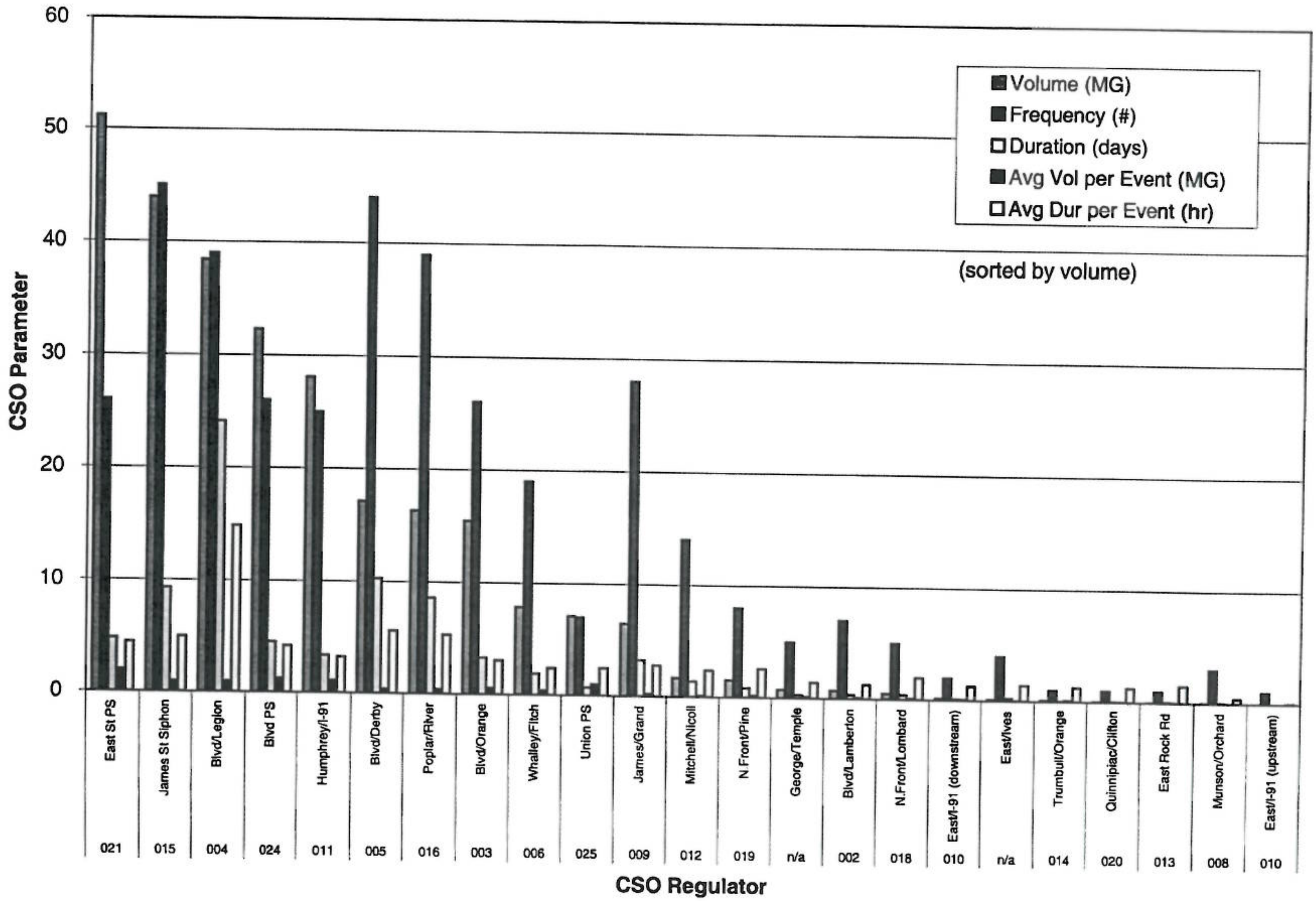


Fig4-10

TABLE 4-11
Stormwater Discharges for the Annual Simulation (MG)

	Quinnipiac River	Mill River	West River	New Haven Harbor
Runoff Volume (MG)	580	310	1260	960

TABLE 4-12
Flow Through East Shore WPAF During Average Year

Location	Volume Treated (MG)	Peak Influent Rate (mgd)
East Shore WPAF	11,500	103

Receiving Water Flows

As previously noted, a year with data representative of an average rainfall year was selected for use in the annual simulation (see Appendix B). This section details how flow estimates were obtained for the Quinnipiac, Mill, and West Rivers for the average year.

Quinnipiac River

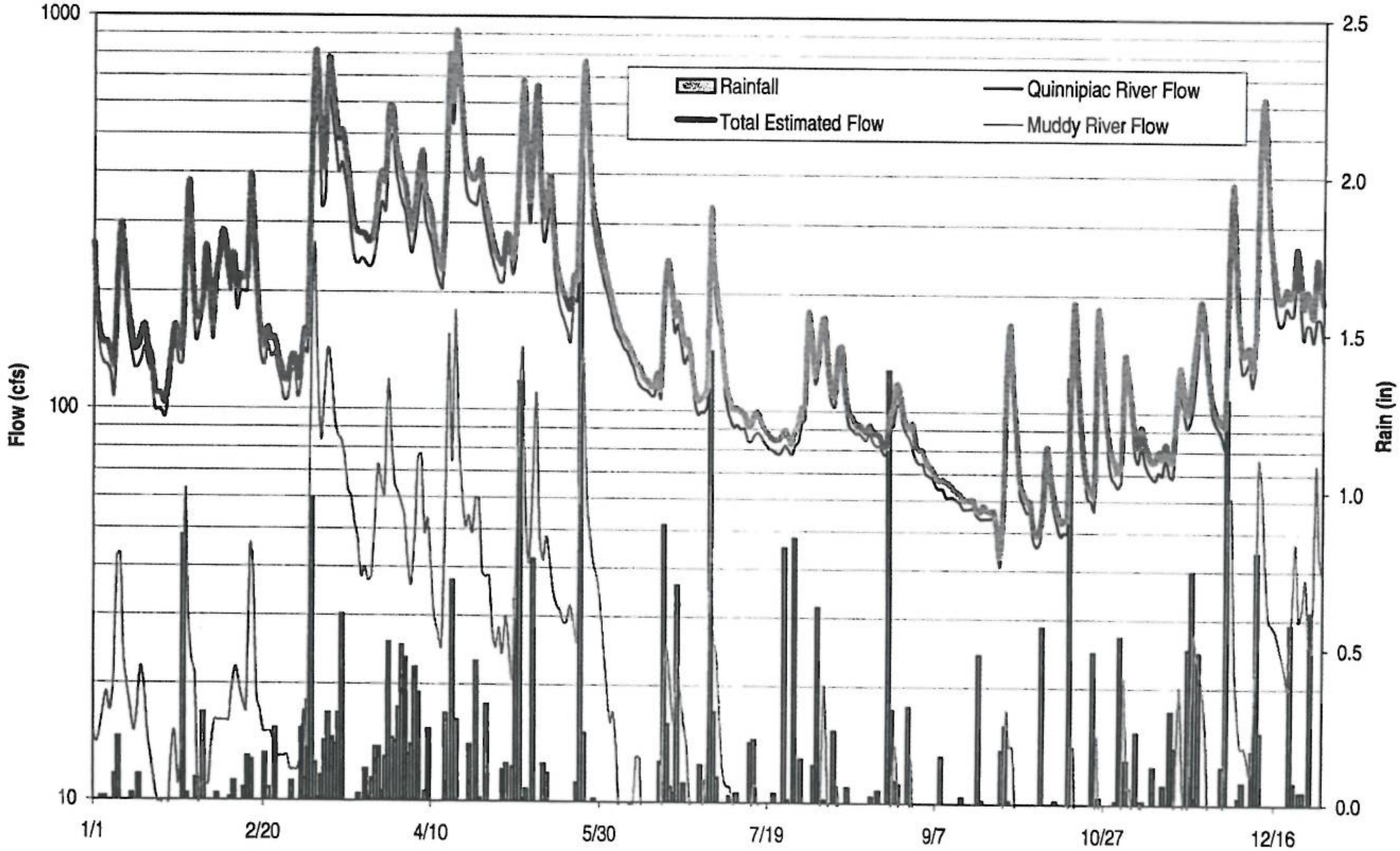
USGS river gauges at Wallingford, Connecticut and at Muddy River provide data for the Quinnipiac River. Daily river flow data were available from January 1, 1967 to September 30, 1997 for the Wallingford Station, and from September 1, 1962 to September 30, 1973 for the Muddy River station. The Wallingford Station measures flow from a large portion of the Quinnipiac watershed upstream of New Haven; the Muddy River station measures a small portion of the watershed. The 1967 flow just north of New Haven was estimated by linearly combining the 1967 records from both stream gauges. This estimate may be low since flow from Wharton Brook and areas along the main stem downstream of the Wallingford station are not included in any of the data. However, based on the percentage of the watershed with data, it is not expected that there would be more than a 13% flow increase as a result of these unaccounted watershed areas.

Figure 4-11 shows the river flows superimposed with the daily rainfall data for 1967. Table 4-13 lists the statistical parameters characterizing the flow in the Quinnipiac during the 1967 year.

Mill River

There are no direct measurements of flow along the Mill River during 1967. However, the SCCRWA has daily measurements of the Lake Whitney surface elevation relative to the crest of the dam spillway for this year. Since Lake Whitney is located in the southern part of Hamden, just north of the New Haven border, estimating flow over the dam spillway allows a reasonable estimate of flow as the Mill River enters the City of New Haven.

Figure 4-11
Quinnipiac River Flow and New Haven Rain Data, 1967



GNH0006-084

During the years 1974 to 1978, the USGS established a stream gauging station below the Lake Whitney spillway. Using this flow data in conjunction with the SCCRWA lake level data during the same period, a correlation was established between lake level and flow (see Figure 4-12). The average daily lake level data provided by the SCCRWA for 1967 was then used to estimate daily flows. These flow estimates are shown in Figure 4-13, along with the 1967 New Haven rainfall data.

Table 4-13 lists the flow characteristics in the Mill River during the 1967 year. Flows in the Mill River are dependent on the volume of water withdrawals from Lake Whitney for drinking water purposes. Since the lake was used as a source of drinking water in 1967, seasonal flow variations shown in Figure 4-11 are not completely dependent on seasonal rainfall variations. Although Lake Whitney has not been used as a source of drinking water since 1992, plans are underway to reinstate the lake as a source. The SCCRWA proposes average future withdrawal rates on the order of 5 to 10 mgd, similar to the 1967 recorded withdrawal rates. Thus, the average yearly flow presented here is expected to be representative of future flows.

West River

Of the three rivers, the West River has the smallest amount of associated flow data. Lake Dawson is part of the West River system and is one of the last lakes feeding the river north of New Haven. Flow in the West River at the New Haven/Woodbridge border was estimated by gauging the flow from Lake Dawson. Since the lake is used by the SCCRWA as source of drinking water, the water quality is closely monitored. Lake elevation was observed daily until the early 1990s, after which weekly observations were made. Using a weir discharge equation, it was possible to estimate flow over the dam spillway based on these observed elevations, assuming negligible dam leakage. Unfortunately, Lake Dawson was drawn down for dredging purposes during 1967 so that flow estimation based on lake level was impossible. An alternative average year was used instead.

The year chosen to estimate flow in the West River north of New Haven was 1993. There are two reasons for this. First, 1993 is considered to be an average year in terms of rainfall[4]. Second, the SCCRWA indicates that there is significant leakage through the dam itself. Leakage was not measured until 1992. So although there are only weekly observations of water surface elevation available during 1993, it was decided that for estimating yearly flows, evaluating leakage was more critical than evaluating daily discharges.

Flow from Lake Dawson enters the West River from three primary sources: flow over the dam spillway, and flow from two channels that capture and discharge dam leakage. Flow over the dam spillway was calculated using a standard weir equation for which the SCCRWA provided discharge coefficients based on stage height. Leakage in the channels is regulated using standard weirs. The SCCRWA observed stage height above the weir crests once a month, and based on the 1993 observations, it remained relatively constant throughout the year. An average leakage flow was estimated based on the average stage elevation, the weir width, and standard published discharge coefficients (Henderson, 1966). The total flow from Lake Dawson was estimated by summing the discharges from each of the three sources.

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[4] An analysis similar to that described in Appendix B for New Haven data was performed using rainfall data from Hartford's 40-year (1954-1994) Bradley Airport data set. The analysis identified 1993 as a year representative of average rainfall conditions.

Figure 4-12

Mill River, Discharge vs Lake Level, 1974-1978

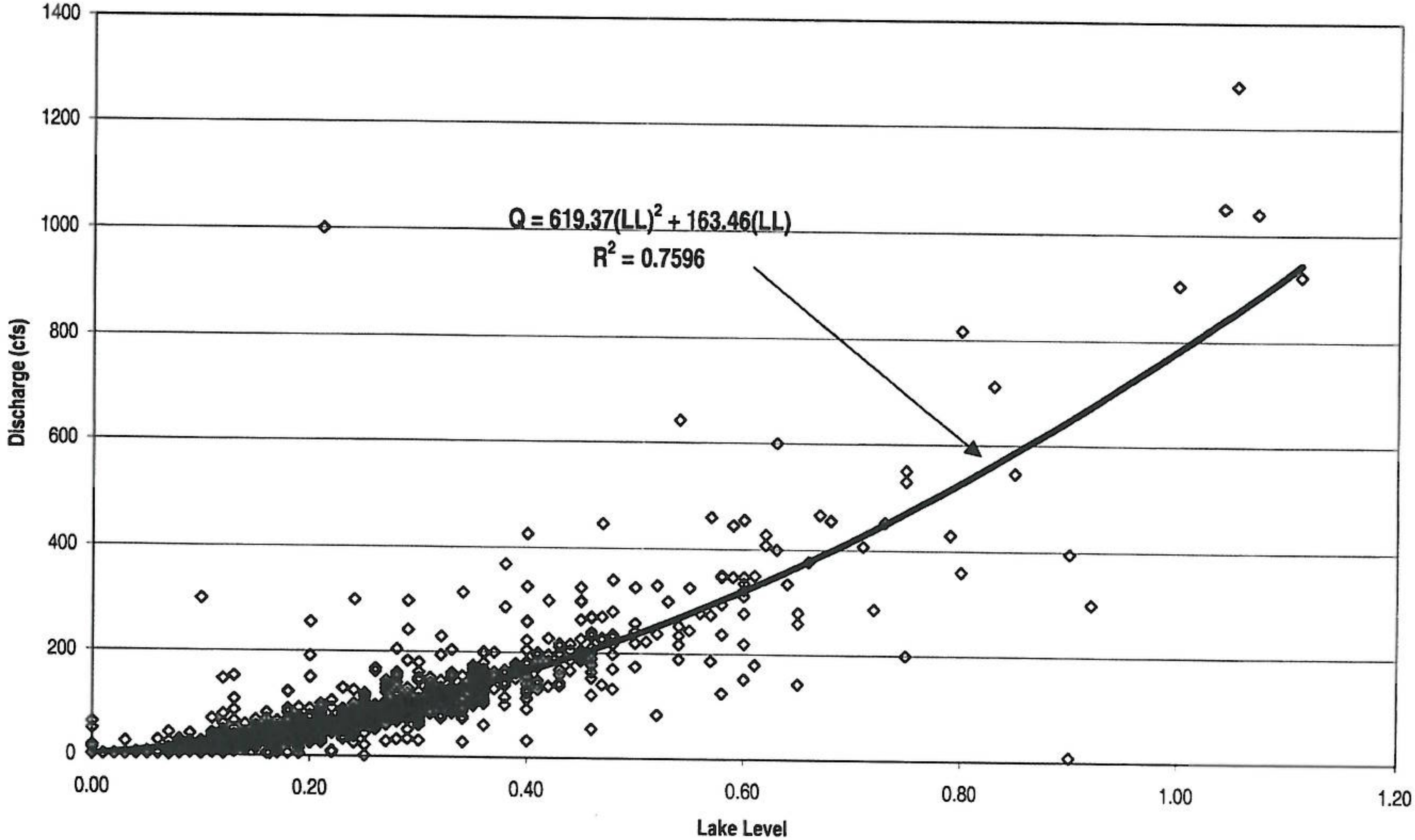
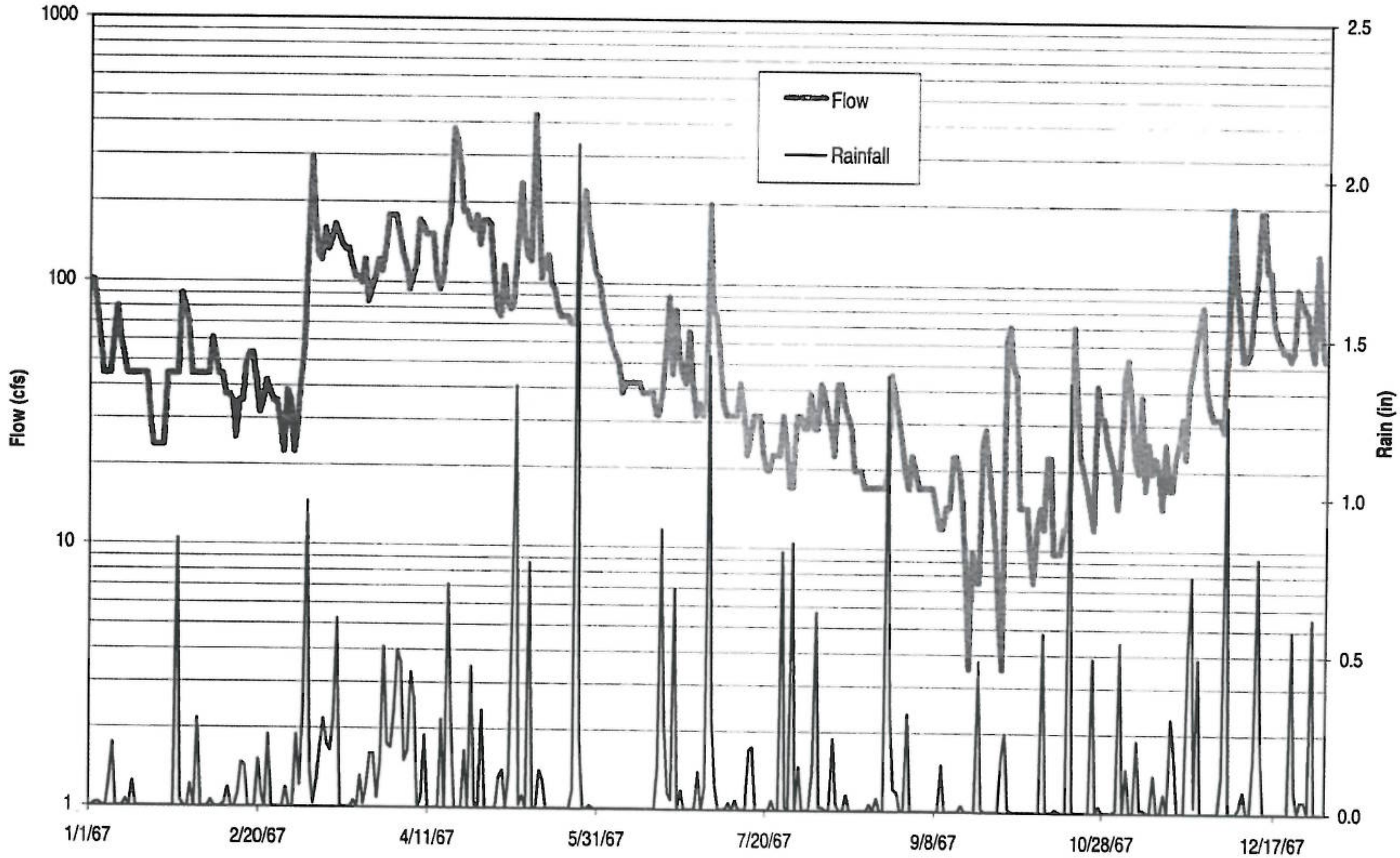


Figure 4-13
Mill River Flow and New Haven Rain Data, 1967



GNH0006-087

Statistical flow parameters associated with the West River in 1993 are shown in Table 4-13. Figure 4-14 illustrates flow variation over the year. Since Lake Dawson is a reservoir, flow fluctuation may not necessarily correspond directly to precipitation.

Estimated average flows may not necessarily reflect future average flows. Since Lake Dawson is an active reservoir, predicting future flows is difficult because they are influenced by the practices of the SCCRWA. However, it is noted that Lake Dawson is primarily used during drier weather; for average years of precipitation, withdrawal rates are not expected to differ significantly from the 1993 rates.

TABLE 4-13
Flow Characteristics of the Quinnipiac, Mill, and West Rivers During the Average Year

River	Minimum Flow (mgd)	Average Flow (mgd)	Maximum Flow (mgd)	Median Flow (mgd)	Total Annual Flow (MG)
Quinnipiac River	28	128	585	94	46,830
Mill River	2	42	274	28	15,160
West River	5	18	157	12	6,690

New Haven Harbor

The total flow for the New Haven Harbor for the average year was estimated by summing the flows for the Quinnipiac, Mill, and West Rivers. The river flows plus the flows associated with stormwater, CSO, and the WPAF gave a total flow for the average year for New Haven Harbor of 71,010 MG.

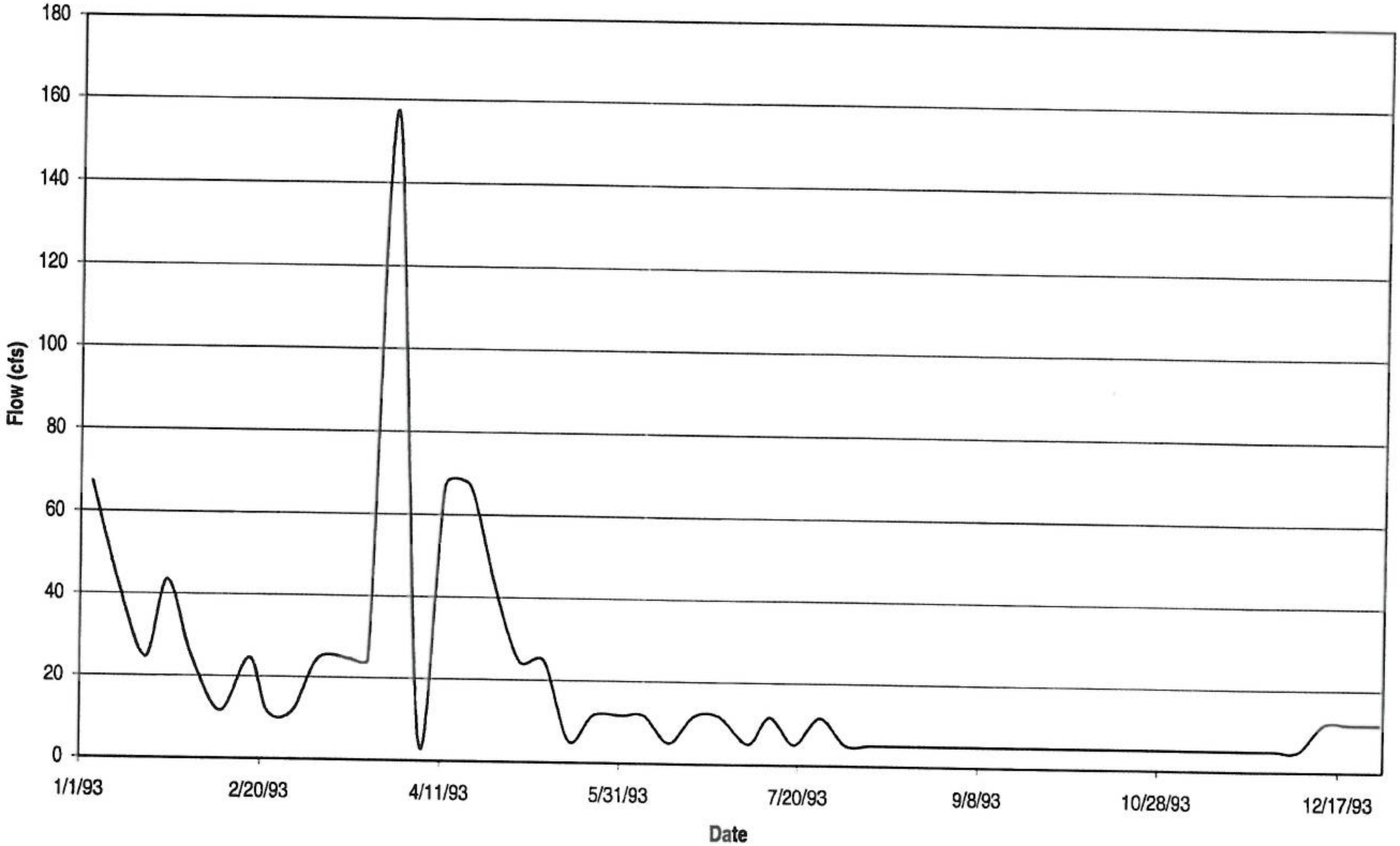
Summary

The following table summarizes the volumes entering the receiving waters from each of the flow sources for the average year.

TABLE 4-14
Flow Volume Summary for the Average Year, Baseline Conditions (MG)

Flow Source	Quinnipiac River	Mill River	West River	New Haven Harbor
River Inflow	46,830	15,160	6,690	71,010
CSO	60	40	80	60
Stormwater	580	310	1,260	960
East Shore WPAF	—	—	—	11,500
Total	**47,470**	**15,510**	**8,030**	**83,530**

Figure 4-14
West River Flow Downstream of Lake Dawson



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Event Mean Concentrations

The four primary sources of contamination to receiving waters that were previously identified included:

- Stormwater runoff
- Combined sewer overflows
- The East Shore WPAF
- Upstream sources

The volume, frequency, and duration of discharges for these sources were described in Section 4. In this section, the contents or quality of these discharges are identified. The parameters used to quantify levels of contamination are fecal coliform, BOD, TSS, TN, and dissolved oxygen. This section establishes event mean concentrations (EMCs) for stormwater, CSOs, and WPAF discharges. In Section 7, these EMCs, coupled with the volumetric data (from Section 4), are used to estimate each source's relative contribution to pollutant loads in each of the receiving waters.

EMCs are defined as the total constituent mass discharge divided by the total volume of flow. Pollutant concentrations vary within a given storm event. Typically, during a storm, the concentrations in the flow are noticeably higher in the beginning of the storm than later in the storm. The elevated concentration levels in the beginning of a storm are known as the "first flush" phenomenon. Since modeling variations in concentration over a variety of storms is a complex undertaking, a single concentration value is typically used to represent overall stormwater or combined sewer overflow quality. This concentration value is known as the EMC. The following sections describe the water quality data gathered and the EMCs recommended for calculating pollutant mass loadings. Each source's relative contribution to receiving waters with respect to each of these parameters is then estimated in Section 7.

Data Sources

This section describes the data gathered to determine event mean concentrations of water quality parameters in CSOs, stormwater runoff, and treatment plant discharges. Water quality sampling data from literature and other studies were gathered to characterize CSO and stormwater discharges. They included previous CSO facility planning studies conducted by CH2M HILL as well as literature data from the United States Geological Survey and United States Environmental Protection Agency. Data from the WPAF effluent discharges were also evaluated. The data were entered into an electronic database for review and statistical analysis. The locations of the WPAF and CSO and stormwater sampling sites were shown previously in Figure 3-1.

New Haven Studies

Water quality data collected in New Haven were limited. Stormwater quality data during wet weather reported by industrial dischargers in 1996 to the CTDEP were evaluated

(CTDEP 1996). Provisional data from residential stormwater from the Yale School of Forestry and Environmental Sciences were also evaluated (Yale University 1998). For CSO, the facility plan completed for the City of New Haven (Cardinal Engineering Associates 1981) contained sampling data collected from the combined sanitary sewer during wet weather events in 1977. One subcatchment was mostly residential while the other was a mixture of residential, commercial, and industrial land uses. Samples collected were analyzed for pH, BOD, suspended solids, total fecal coliform, and organic and inorganic carbon.

In 1991, a report was completed for the *New Haven Harbor, Summer 1990 Water Quality Sampling Program* (Metcalf & Eddy 1991). The report summarized water quality sampling data collected in 1990 in the New Haven Harbor, the West Haven WPCP, and the East Shore WPAF. The data were collected during dry weather conditions. Conventional water quality parameters including total nitrogen, phosphorus, bacteria, BOD, and others, were analyzed.

Previous Studies

Water quality data acquired for recent CSO and stormwater studies by CH2M HILL were gathered for review. These data were gathered to demonstrate the similarities and ranges of data collected in other communities. The water quality data were gathered in the field and from general literature during the development of CSO facility plans for the cities of Bangor, ME (CH2M HILL 1991), Portland, ME (CH2M HILL 1992a), and Providence, RI (Louis Berger & Associates 1993). EMCs for the CSO facility plans in Portland, OR (CH2M HILL 1990) and Boston, MA (CH2M HILL 1989a, 1989b) also were reviewed for comparison.

USGS and USEPA Databases

Water quality data for CSO and stormwater from USGS and USEPA literature (USGS 1984-1995; USEPA 1983) were also gathered to review examples of the range of concentrations found in CSO and stormwater. These databases normally cover a wide range of cities, regions, and land uses. USEPA's *Results of the Nationwide Urban Runoff Program* (NURP) (USEPA 1983), for example, is a good data source for this comparison.

EMCs for Combined Sewer Overflows

Overview

The CSO water quality data for New Haven, Bangor, Portland, and Providence were analyzed. Previous CSO planning reports for each of these cities were reviewed. The CSO data presented in these reports for BOD, TSS, fecal coliform, and TN are summarized in Table 5-1. The minimum, average, mean, and maximum values are listed. The mean for fecal coliform is the geometric mean, while arithmetic means are used for the other parameters. Graphical comparisons of the BOD, TSS, and fecal coliform data are presented in Figures 5-1, 5-2, and 5-3, respectively. EMCs were developed from the data for each pollutant of interest. These mean concentrations will be used to calculate New Haven CSO loads.

Table 5.1
Statistical Summary of Combined Sewer Overflow Water Quality Data

				BOD (mg/L)				TSS (mg/L)				Fecal Coliform (units as shown)				TKN (mg/L)			
Study Location	**Study Period**	**No. of Sites Sampled**	**Sampling Events**	No. Data	Low	Average	High	No. Data	Low	Average	High	No. Data	Low	Geometric Mean	High	No. Data	Low	Average	High
New Haven[1]																			
Area B-3a	8/17/77	1	1	16	90	260.6	700	16	105	201.7	358	Not Analyzed				Not Analyzed			
	9/24/77	1	1	8	196	390	780	8	201	229.1	240	Not Analyzed				Not Analyzed			
Area E-1	10/14/77	1	1	5	81	111.2	137	5	142	163.6	183	Not Analyzed				Not Analyzed			
												(CFU/100mL)							
Bangor, ME[2]	5/15/91 - 5/30/91	5	4	82	4	24.3	105	Wet - 93	4	230.2	1000	Wet - 74	7.00E+03	1.71E+05	5.40E+06	Not Analyzed			
												E-Coli (CFU/100 mL)							
Portland, ME[3]	5/21/92 - 8/22/92	5	2	Wet[3] - 20	10	77.8	500	Wet[3] - 20	37	232.05	1100	Wet[3] - 20	100	372950	1600000	Wet[3] - 20	1	7.3	18
												(MPN/100mL)							
Providence, RI (NBC)[4]																			
Area A[5]	10/23/84 - 9/22/90	4	15	208	8	69.6	371	179	6.8	107	861.3	89	1.00E+03	8.03E+05	1.90E+07	Not Analyzed			
Area B[6]	5/17/86 - 10/3/86	6	30	111	2	37.7	240	110	1	87	1800	106	4.00E+02	1.39E+06	1.10E+08	Not Analyzed			
Area C[7]	4/28/87 - 9/22/90	4	11	49	5	69.5	380	48	11.5	87.1	1050	49	2.00E+03	1.15E+06	1.10E+08	Not Analyzed			
Area D[8]	5/10/89 - 10/2/89	4	13	38	33	180	378	50	20	182	900.8	28	2.30E+06	1.04E+07	4.60E+07	Not Analyzed			
Area 2[9]	7/12/90 - 10/13/90	6	11	52	6	75.4	556	48	7	135	973.3	51	2.30E+03	1.20E+06	2.40E+07	Not Analyzed			
Area 067[10]	10/27/88 - 6/13/89	1	3	8	6	36.3	86	16	10	60.8	225.3	15	5.00E+04	3.33E+05	9.60E+05	Not Analyzed			
Area BPSA[11]	4/12/91 - 8/9/91	5	25	125	3	71.9	480	125	8	95.3	446	125	2.00E+03	8.65E+05	1.60E+07	Not Analyzed			
Areawide Average	-	-	-	-	-	70.5	-	-	-	105	-	-	-	9.49E+05	-	Not Analyzed			
EPA Study[12]					59	115	222		273	370	551								

Data Sources:
[1] Cardinal Engineering Associates (1981)
[2] CH2M HILL (1991a)
[3] CH2M HILL and Dufresne-Henry (1993). The 20 data points are for 20 composite samples representing 160 grab samples.
[4] Louis Berger & Associates (1993)
[5] Area A: Metcalf & Eddy (1986) and University of Rhode Island (1990)
[6] Area B: O'Brien and Gere (1988) and University of Rhode Island (1990)
[7] Area C: Camp Dresser and McKee (1989) and University of Rhode Island (1990)
[8] Area D: Greeley and Hansen (1991)
[9] Area 2: University of Rhode Island (1990)
[10] Area 067: University of Rhode Island (1990)
[11] Area BPSA: BETA/CH2M HILL Team (1991)
[12] USEPA (1977)

Figure 5-1. Summary of CSO Water Quality Data for BOD

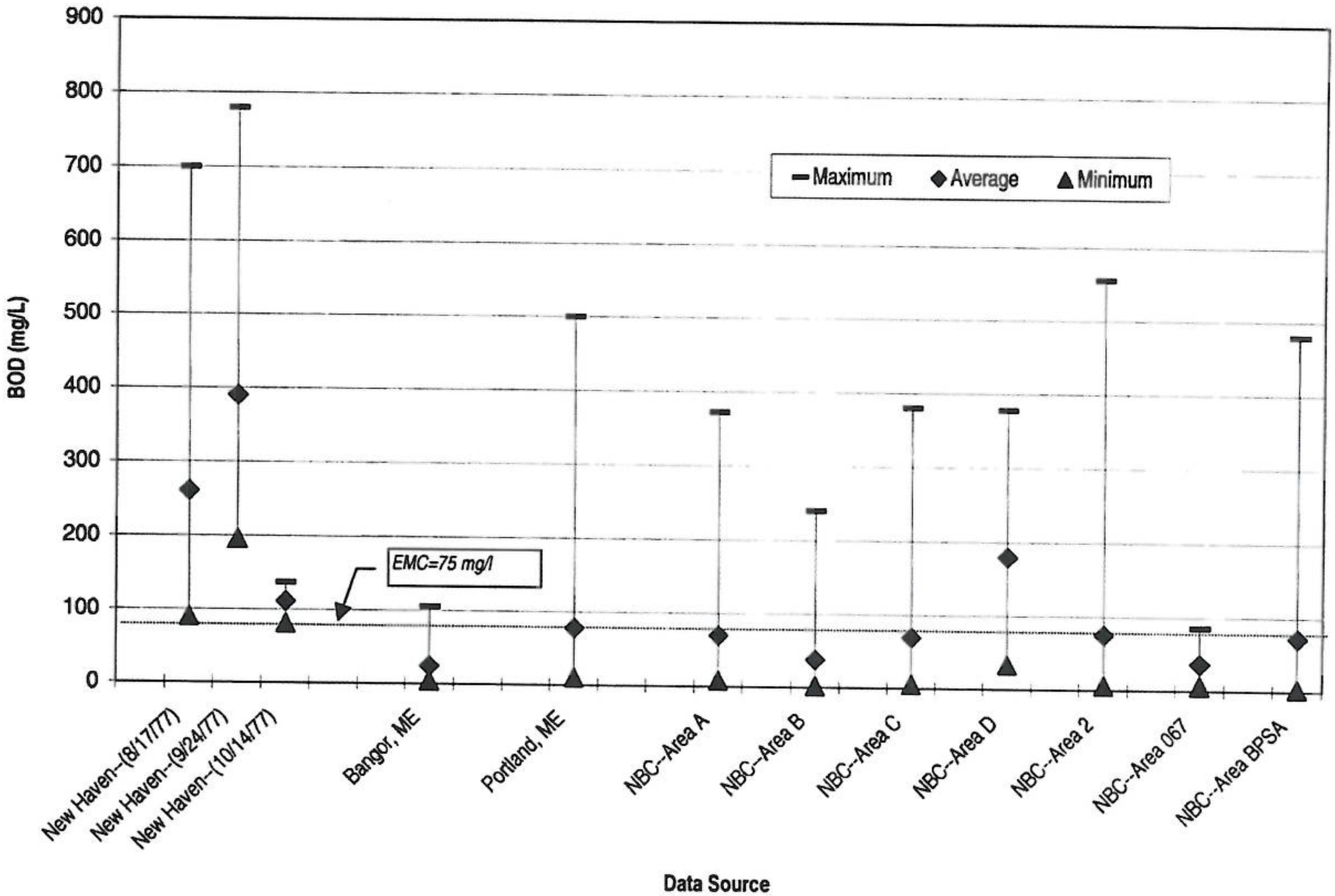

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Figure 5-2. Summary of CSO Water Quality Data for TSS

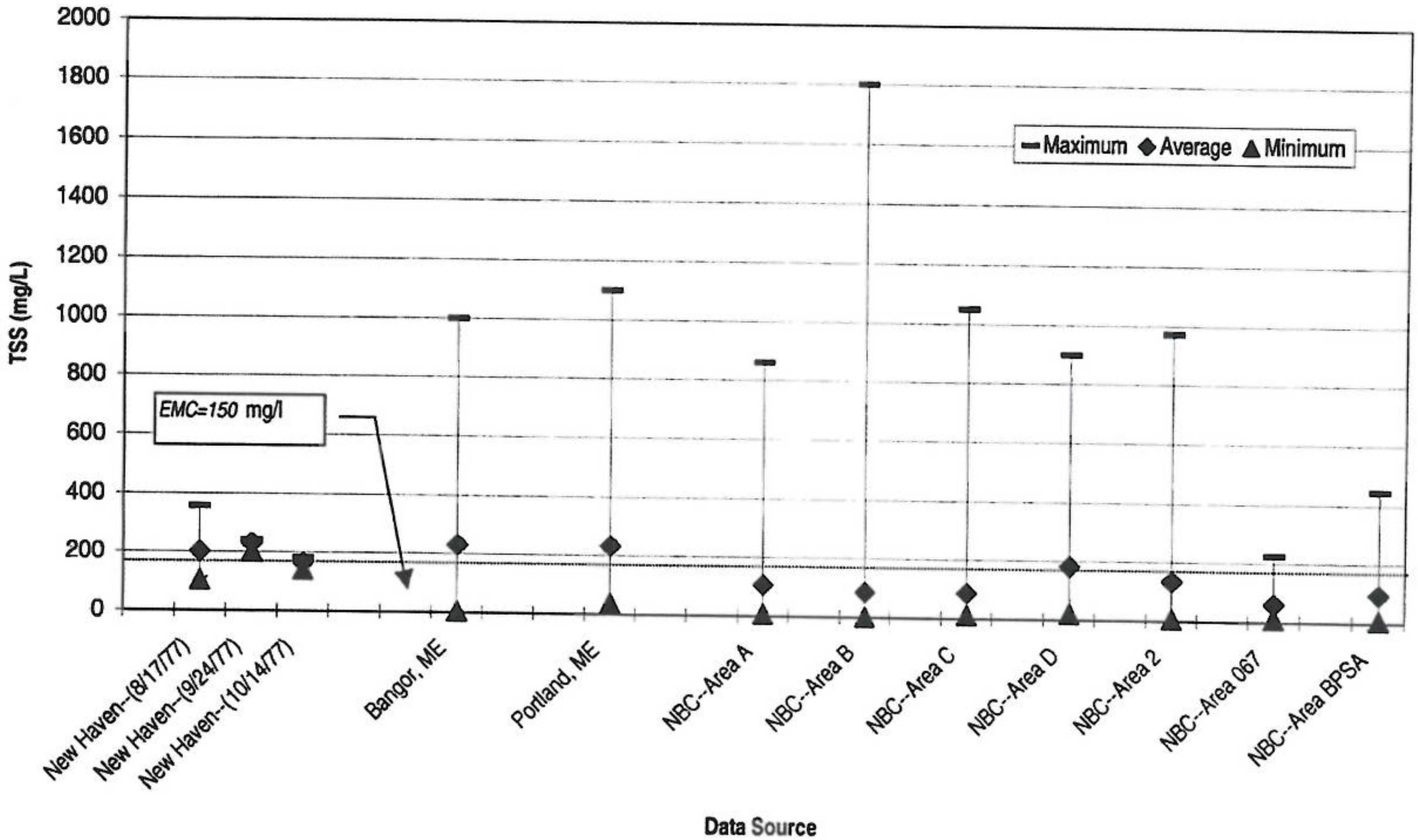
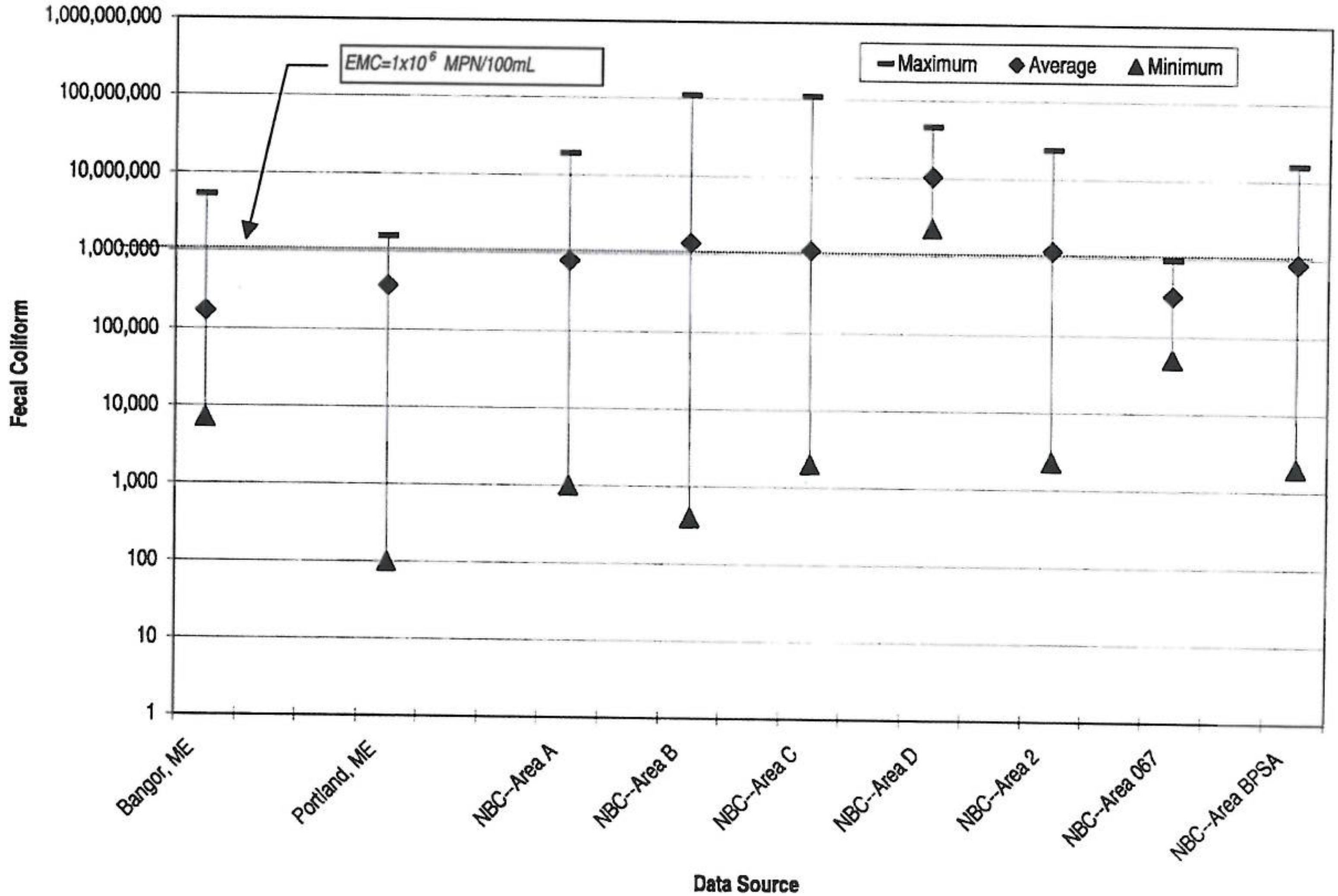


Figure 5-3. Summary of CSO Water Quality Data for Fecal Coliform



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New Haven Data

The New Haven CSO water quality data were obtained from the 1981 Facility Plan (Cardinal Engineering Associates 1981), which reported data for three storms in 1977. In this study, CSO samples were collected at two sites named B-3a and E-1, corresponding to the name of the subcatchment each represents. Subcatchment B-3a is part of Subcatchment B-3, which is tributary to CSO 002 (see Figure 4-1 for location of outfalls). It is part of the Boulevard drainage basin and is mostly residential. Subcatchment E-1 is tributary to CSO 007. (CSO 007 was later eliminated through sewer separation.) It is part of the East Street drainage basin and is a mixture of residential, commercial, and industrial land uses. Sampling was accomplished through the use of a discrete portable sampler installed in a manhole upstream of the overflow structure. Samples were collected at B-3a during storms of August 17 and September 24, 1977. Samples were collected during one storm at site E-1 on October 9, 1977. Table 5-1 summarizes the data reported for these three storm events.

In the facility plan, CSO pollutant loads were calculated using average literature values instead of using values derived from the CSO sampling data. The report states that the high sampled BOD values reflected the first flush, which would in most cases be treated at the WPAF. The average literature values used in that report (obtained from USEPA 1977) were 115 mg/L for BOD and 370 mg/L for TSS.

During the sampling, combined sewage flow rates were measured upstream of the overflow weir, and therefore they included dry weather flows. CSO sampling data for the August 17, 1977, event included samples collected before significant rainfall occurred and after significant runoff had ended. For the September 24, 1977, event, rainfall was relatively light until 200 minutes after the start of sampling. Combined sewage flows did not increase significantly until after 240 minutes. Seven of the eight samples collected during this event were collected before 200 minutes had passed, and are therefore more representative of sanitary sewage than combined sewage. For the third event, October 14, 1977, the first sample was taken before significant rainfall had occurred; however, the remaining samples were taken during periods of elevated combined sewage flows. In summary, average BOD and TSS concentrations in the New Haven data set are skewed by the inclusion of a large number of samples collected before or after elevated combined sewage flows had occurred. These data are included in Figures 5-1 and 5-2; however, the fact that the data includes values for sanitary sewage was taken into account when selecting EMCs.

Previous Studies

Bangor, Maine

The CSO water quality data for Bangor was obtained from the Bangor CSO Facilities Plan (CH2M HILL 1991a and 1991b). Samples were collected for four rainfall events between March and May 1991 at CSO regulator locations CS1, CS2, CS3, CS4, and CS5. The CSOs selected for sampling generate high overflow volumes and were considered to have the greatest effect on the receiving waters. Land uses in the tributary areas of these CSO regulators were representative of the combined sewer areas throughout the City of Bangor: CS1 is mainly residential, parks, and industrial; CS2, CS3, and CS4 are mainly residential and commercial; and CS5 is mainly residential. The sampling procedure was designed to obtain samples that would characterize pollutant concentrations over the entire flow hydrograph.

For each storm event, two grab samples were collected on the rising limb of the overflow hydrograph and three on the falling limb, and at least two grab samples were taken during the first 2 hours of the storm event. The data did not show any significant variation between sampling locations that would indicate a relationship between CSO water quality and land use. The Bangor study included a first flush analysis for TSS and *E. coli*. A consistent first flush effect was seen for TSS but not for *E. coli*. Estimated CSO pollutant loads were calculated using EMCs derived from the sampling data: 24.5 mg/L for BOD, 250 mg/L for TSS, and 181,000 CFU/100 mL for fecal coliform. For the Bangor data, the calculated EMCs were similar to the arithmetic averages.

Portland, Maine

For Portland, Maine, CSO water quality sampling data were obtained from the Master Plan (CH2M HILL 1992). The sampling program covered two storm events, one in June and one in July 1992. Five CSO sites were sampled. The sites were chosen based on the size of the drainage area, land use within the drainage area, receiving water, hydraulic characteristics of the diversion structure, and frequency of overflows. The land use characteristics for each site are: CS1, suburban residential/commercial; CS2, suburban residential; CS3, industrial, commercial; CS4, high-density urban; and CS5, urban residential. For each storm, 16 samples were collected at each site. The samples were analyzed to determine when the "first flush" was complete. Then they were combined to produce one composite sample during the first flush and one composite sample after the first flush for each site. The composite samples were analyzed for the pollutants of concern. Significant variations in data between sites were not observed, except that the concentrations for CS2, which represented a small residential area, were consistently lower than for the other sites. Estimated CSO pollutant loads were calculated using EMCs derived from the sampling data: 34 mg/L for BOD, 217 mg/L for TSS, 430,000 CFU/100 mL for *E. coli* and 5 mg/L for TKN.

Providence, Rhode Island

The CSO water quality data from the facility plan for Providence were summarized from various sampling programs over a period of years from 1984 to 1991. Sampling data were collected in seven subcatchment areas. The number of locations and storm events sampled are summarized in Table 5-1. The sampling data from the various sources were compiled and analyzed during the Providence facilities program and reported in the Concept Design Report (Louis Berger & Associates 1993). System-wide averages were calculated from the seven individual area values. The CSO pollutant concentrations used to calculate pollutant loads were 70.5 mg/L for BOD, 105 mg/L for TSS, and 106 MPN/100 mL for fecal coliform.

Selected EMCs for New Haven CSO

Comparing the New Haven CSO water quality data to those for Bangor, Portland, and Providence, the extent of sampling and the size of the available data set for New Haven is small. As seen in Figure 5-1, the BOD values for New Haven were high compared to those in the other studies. This may reflect a pronounced first flush effect, as theorized in the 1981 report. The TSS values for New Haven (Figure 5-2) fall within the range of values reported in the other cities. Fecal coliform and nitrogen were not measured in the New Haven study.

The water quality of CSO is highly variable, as documented in previous CSO studies and EPA literature. Due to this variability, a large set of data is desirable for EMC development.

Because the New Haven data set was very small, the selection of EMC values for New Haven was based on examination of the data from the various studies presented above. These data sets represent conditions similar to New Haven: small- to medium-size cities in New England with a variety of land uses. Table 5-2 lists the concentrations used to calculate CSO loads for each of the studies discussed above; for comparison, values from two other studies—Portland, OR and Boston, MA—are also included, as well as the averages from the New Haven data. The EMC values selected for New Haven are also presented in Table 5-2. The New Haven EMCs for BOD and TSS were selected based on visual examination of the data presented in Figures 5-1 and 5-2. For both parameters the selected EMCs fall within the range of EMC values used in the previous studies. For fecal coliform, the New Haven EMC was selected based on examination of the data presented in Table 5-1. Although there are limited data concerning TKN concentrations in CSO, there are no data concerning TN concentrations. Therefore, the selected EMC for TN was based on a weighted average between the reported values of influent sewage and stormwater runoff TN concentrations. TN concentrations are estimated to be 21 mg/L.

TABLE 5-2
Comparison of Selected EMCs for CSO Load Calculations

		Parameter			
Study Source	**Basis of Selected Concentration**	**BOD (mg/L)**	**TSS (mg/L)**	**Fecal Coliform (MPN/100 mL)**	**TN (mg/L)**
Bangor, ME	EMC	24.5	250	180,000	—
Portland, ME	EMC	34	217	—	—
Providence, RI	Mean	70.5	105	1,000,000	—
Portland, OR	Mean	30	148	160,000	—
Boston, MA	Mean	90	188	680,000	—
New Haven Selected EMCs	EMC	75	150	1,000,000	21
CTDEP Surface Water Standards	Class A Inland Surface Waters	n/a	n/a	100[1]	n/a
WPAF Wet-Weather Effluent Limits	CTDEP Permit dated 10/24/95 and CTDEP Permit Appeal Letter dated 10/28/94	40.0[2]	40.0[2]	200[3]	n/a

[1] Monthly moving arithmetic mean for most recent 12 months for total coliform. No individual sample can exceed 500 MPN/100 mL.

[2] Average Monthly Concentration for wet weather. The Maximum Daily Concentration in wet weather is 90.0 mg/L.

[3] Geometric mean for samples collected over 30 days. The geometric mean of samples collected over 7 days cannot exceed 400 MPN/100 mL.

EMCs for Stormwater

Overview

This section contains an analysis of water quality data for stormwater in New Haven. Data from recent studies conducted by the CTDEP and by the Yale School for Forestry and Environmental Sciences are presented and discussed. The New Haven data is compared to data from other studies, namely NURP, Boston, and Providence studies. Data from New Haven and other studies were used to estimate EMCs for stormwater in New Haven.

Samples collected by the CTDEP and Yale are all grab samples, taken within the first half-hour of runoff in a storm event. Hence, due to insufficient data concerning the time variation of parameter concentrations over storm events, the New Haven data do not make use of the first flush concept. The other studies presented, however, take the first flush phenomenon into consideration.

New Haven Data

Industrial dischargers, as part of the general stormwater permit, collected stormwater data and reported it to the CTDEP. There were about 40 different sites surveyed and a total of 117 samples taken from November 7, 1995 to June 30, 1998. Each site is classified as industrial. The Yale School for Forestry and Environmental Sciences collected data at two locations from June 1 to September 28, 1998. Thirteen grab samples were taken at each site. The land type from which Yale collected the stormwater is mostly residential.

The CTDEP water quality samples were collected at a number of storm outfalls which discharge to the four receiving water bodies in New Haven: Quinnipiac River, Mill River, West River, and New Haven Harbor. Samples were collected in catchments from roof drains, driveways, parking lot, and surface drainage abutting the industrial complex. The Yale sites are located in a stormwater pipe just before its outfall to the West River near Whalley Avenue and in a small runoff channel at the Beaver Ponds outlet near Fitch Street. Locations of these sites were shown previously in Figure 3-1.

While specific parameters studied in the other sections of this technical memorandum deal with BOD, TSS, fecal coliform, and TN, this section pertains to TSS, fecal coliform, TN, and COD, not BOD. There is no information concerning New Haven stormwater BOD concentrations. The stormwater permit requires that COD, not BOD, be sampled and the Yale study measured neither COD nor BOD.

The average values and ranges of New Haven stormwater concentrations are shown in Table 5-3. The data are discussed in detail in the following subsections.

COD

The average COD concentration measured was 48 mg/L, with a range of 1 to 530 mg/L. The standard deviation from the mean was about 77 mg/L indicating a high variability between sites and measurements. The median value of COD was found to be 30 mg/L. The relationship between COD and BOD is water-specific and uncertain at this point. However, if similar trends found in the NURP study are assumed (i.e., a 1:6 ratio of BOD to COD), stormwater has insignificant amounts of BOD.

TSS

The average TSS in the stormwater was found to be 47 mg/L, with a range of 1 to 432 mg/L. A standard deviation of 81 mg/L illustrates the high variability between sites. The median value of TSS is 26 mg/L. The state standards for water treatment plants require that the monthly average discharge of TSS concentrations into a receiving body of water should be no greater than 30 mg/L. Although the median indicates that greater than 50 percent of the waters meet state effluent standards, overall stormwater runoff is of poorer quality than effluent from treatment plants.

TABLE 5-3
Water Quality of Stormwater in New Haven Sampled from Industrial Sites and the Westville Area

Effluent Parameters	Minimum	Median	Average	Maximum
Storm Magnitude (in.)	0.1	0.7	1.0	3.2
COD (mg/L)	1.0	30	58.5	530
TSS (mg/L)	0.5	26	46.6	432
Fecal Coliform (MPN/100 mL)	ND	100	590[1]	680,000
TN (mg/L)	0.3	2.2	3.0	22.1

[1] geometric mean

Fecal Coliform

The geometric mean of fecal coliform is 590 MPN/100 mL of stormwater, with a range of 0 to 680,000 MPN and a median value of 100 MPN. As with TSS and COD, there is a significant amount of variability. CTDEP requires that the geometric mean established for bathing areas be no greater than 33 MPN/100 mL and for shellfish harvesting no greater than 88 MPN/100 mL.

TN

Future regulations for treatment plant effluent may include limiting the average TN discharge to 8 - 10 mg/L. The average concentration of TN based on New Haven data is 3.0 mg/L, with a range of 0.3 - 22 mg/L and a standard deviation of 3.4 mg/L. The average stormwater TN concentration is lower than the anticipated treatment plant effluent limit.

Previous Studies

The water quality data for stormwater from Providence, RI, Boston, MA, and NURP are compiled and summarized in Table 5-4. These projects were chosen because the towns and cities studied have similar land use and a similar socio-economic structure to New Haven. Values reported by these studies represent the arithmetic mean concentration of BOD, TSS, and TN, whereas those for fecal coliform are the geometric mean. Averages taken from the data in New Haven are included for easy comparison. The specifics of the studies are discussed below.

Table 5-4
Statistical Summary of Stormwater Quality Data

				BOD (mg/L)				COD (mg/L)				TSS (mg/L)				Fecal Coliform (MPN/100mL)				Total Nitrogen (mg/L)			
Study Source	Year of Study	Locations Sampled	Sampling Events	No. Data	Low[1]	Arithmetic Mean[2]	High[1]	No. Data	Low[1]	Arithmetic Mean[2]	High[1]	No. Data	Low[1]	Arithmetic Mean[2]	High[1]	No. Data	Low[1]	Geometric Mean[2]	High[1]	No. Data	Low[1]	Arithmetic Mean[2]	High[1]
Providence, RI																							
Area B	1986	-	5	19	< 2	27.0	127	-	-	-	-	19	11.3	37.7	119.0	19	< 1,000	6.63E+04	2.40E+07	Not Analyzed			
Area C	1987	-	1	6	8	38.7	120	-	-	-	-	6	4.6	24.5	46.0	6	< 2	5.55E+03	2.40E+05	Not Analyzed			
Area D	1989	-	3	8	34	119.0	252	-	-	-	-	12	7.0	32.0	57.9	12	4.30E+03	1.66E+05	4.30E+06	Not Analyzed			
Boston, MA	1988	-	-	-	2	23.5	85	-	-	-	-	-	6.0	57.0	550.0	-	-	4.93E+04	-	Not Available			
NURP																							
(New England)	1983	8	-	333	2	52.1	252	68	42	79-107	135	-	4.6	37.8	550	-	-	-	-	57	1.3	2.1-5.2	7.3
(New York)	1983	5	-	Not Analyzed				38	18	25-86	102	-	25	42-294	380	38	9.00E+02	1.00E+04	2.40E+04	125	0.4	0.5 - 2.9	6.0
(EMC for urban sites)	1983	-	-	-	-	10-13	-	-	-	73-92	-	-	-	141-224	-	-	-	(1.00 - 21.0)E+3	-	-	-	2.4-3.1	-
New Haven, CT																							
Industrial Discharges	1996-98	-	-	-	-	-	-	117	1	58.5	530	117	0.5	54.3	432	117	ND	1.52E+02	6.80E+05	118	0.17	3.11	22.1
Yale Provisional Data	1998	2	13	-	-	-	-	-	-	-	-	26	0.7	12.0	123.2	26	100	2.55E+03	3.55E+04	10	1.4	2.25	3.18

[1] High and Low values for the NURP study represent the limits of the 90% confidence interval.

[2] The mean values reported in the NURP study were calculated assuming that the data distribution was lognormal. The following formula was used: Mean = Median x sqrt(1 + (coeff. of variance)^2)

[3] All samples were taken from one location in New Hampshire. The data set may not be a good representation of the New England Area.

Sources:
CH2M HILL (1992, 1989a, 1989b), CTDEP (1996), USEPA (1983), Yale University (1998)

During the Providence CSO facility plan development, stormwater sampling was available in three of the tributary areas. The sampling in Areas B, C, and D was conducted in 1986, 1987, and 1989, respectively. Data from the Boston stormwater-sampling program are also summarized in Table 5-4. CH2M HILL executed this study in 1989. In addition, NURP studies from two areas, New York and New England, as well as the general EMCs reported by NURP, are included in Table 5-4. The NURP study was documented in 1983. The New England study was taken from three locations: Lake Quinsigamond (near Worcester, MA), Upper Mystic (near Boston), and Durham (New Hampshire). The New York study included three areas: Long Island (Nassau and Suffolk Counties), Lake George, and Irondequoit Bay (Rochester area). The general EMCs reported by the NURP study include data taken from around the country at up to 67 locations.

It is noted that pollutant concentrations vary considerably, both during a storm event, and from event to event at a given site. There are also high levels of variation from site to site within an urban area. According to the NURP study, the data variation between sites of similar use (e.g., industrial sites) was far greater than any variation of mean concentrations between areas of different land use (e.g. industrial verses residential). Therefore, there was no statistical difference between industrial and residential rainwater runoff concentrations for TSS, COD or TN. As for fecal coliform, the data in the NURP were too limited to identify any land use distinctions or lack thereof. However, the NURP study (specifically its Baltimore location) conducted small scale site studies which simulated wash-off by storms and identified that a substantial difference in coliform level can result from the general cleanliness of an area, which they associated with the socio-economic strata of the neighborhood.

The NURP study's conclusions are corroborated by recent studies (see Fink 1991 and CDM 1996). Table 5-5 is reproduced from one such study and it indicates that there is little variation of EMCs between areas of differing land use for BOD, TSS, and TKN. As for fecal coliform, the EMCs for industrial and commercial sites are slightly lower than residential sites. It is assumed that New Haven will exhibit similar characteristics.

Generally, the New Haven data indicate that TSS and TN concentrations are comparable to those of previous studies, but fecal coliform concentrations are considerably lower. This may be due to the fact that most of the data concerning New Haven are from industrial areas.

Selected EMCs for New Haven Stormwater

The recommended concentrations for developing nonpoint source pollutants are estimated from Figures 5-4 through 5-7. The figures illustrate the range and averages of EMC concentrations for the various studies outlined above. The dashed line is the proposed EMC for New Haven. The proposed New Haven EMCs are engineering estimates based on the amount of samples taken per study, the quality of the data, and the relevance of the study to New Haven's overall land use and socio-economic structure. The EMCs chosen for New Haven stormwater are shown in Table 5-6.

EMCs for East Shore WPAF

Effluent from the East Shore WPAF is discharged into New Haven Harbor. It receives and treats wastewater collected from New Haven, Woodbridge, Hamden, and East Haven. The plant is designed for an average flow rate of 40 mgd and with a peak capacity of approximately 100 mgd. The treatment processes of the facility include influent screening, grit removal, primary clarification, aeration using the modified Ludzak-Ettinger process for nitrogen removal, secondary clarification, and disinfection with sodium hypochlorite.

Secondary treatment has a maximum capacity of 60 mgd, but flows in excess of 60 mgd are diverted around secondary treatment, blended with secondary effluent, then disinfected before discharge. Although the portion of flow that exceeds 60 mgd is diverted around aeration and secondary clarification (hereto defined as "diversion flow"), it still receives screening, grit removal, primary clarification, and disinfection.

TABLE 5-5

Statistical Information on Stormwater EMCs in Atlanta, GA, Showing Concentrations with Differing Land Use

Land Use		BOD (mg/L)	COD (mg/L)	Fecal Coliform (MPN/100 mL)	TSS (mg/L)	TKN (mg/L)
Residential	# Samp.	40	39	38	36	35
	Min	2.0	2.3	40	4.6	0.4
	Max	92	257	500,000	933	6.3
	Median	10	46	13,000	109	1.4
	Mean	15	65	8,653	178	1.5
Industrial	# Samp.	51	52	49	52	49
	Min	2.0	2.5	2	0.5	0.3
	Max	91	303	1,600,000	580	6.4
	Median	7	42	2,300	46	1.0
	Mean	14	68	2,251	88	1.4
Commercial	# Samp.	50	50	46	52	49
	Min	0.2	3.7	10	4.2	0.2
	Max	82	498	24,000	586	4.9
	Median	7	37	1,840	58	0.8
	Mean	10	58	1,398	129	1.1

Source: CDM 1996

TABLE 5-6
EMCs Chosen for New Haven Stormwater

Parameter	BOD (mg/L)	TSS (mg/L)	Fecal Coliform MPN/100 mL	Total Nitrogen (mg/L)
Event Mean Concentration	50	50	10,000	3.0

Note: For comparison, CSO EMCs are 75 mg/L (BOD), 150 mg/L (TSS), 1,000,000 MPN/100 mL (Fecal Coliform), and 21 mg/L (TN).

Figure 5-4
BOD EMCs for Various Studies

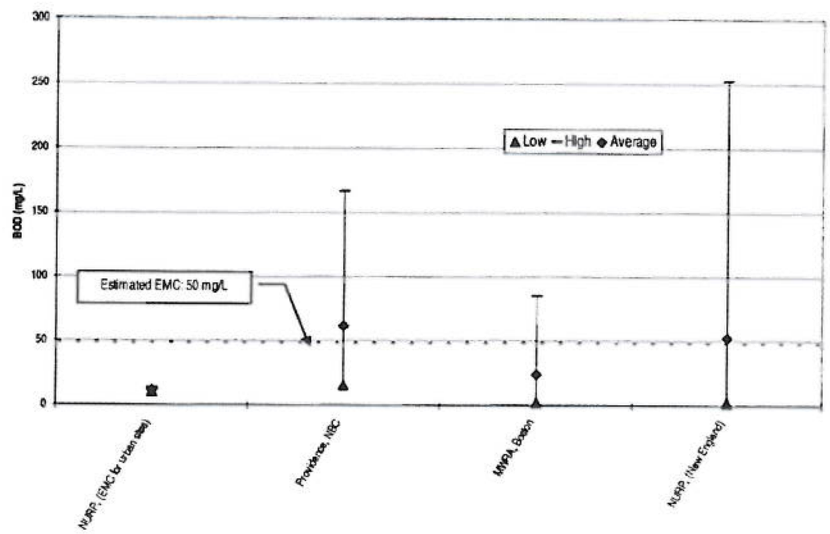


Figure 5-5
TSS EMCs for Various Studies

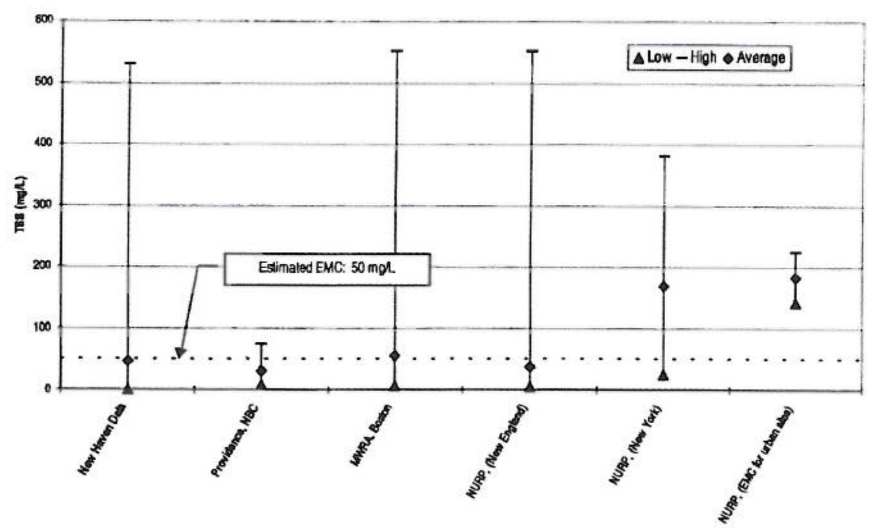


Figure 5-6
Fecal Coliform EMCs for Various Studies

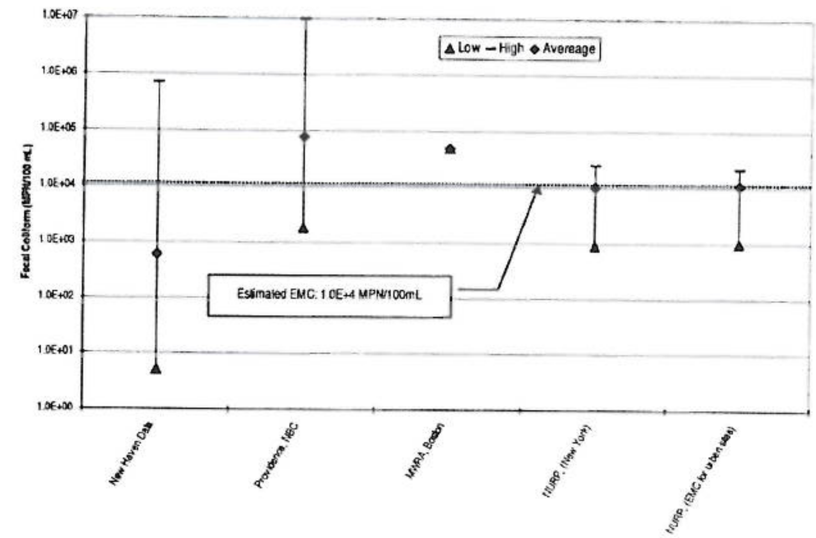
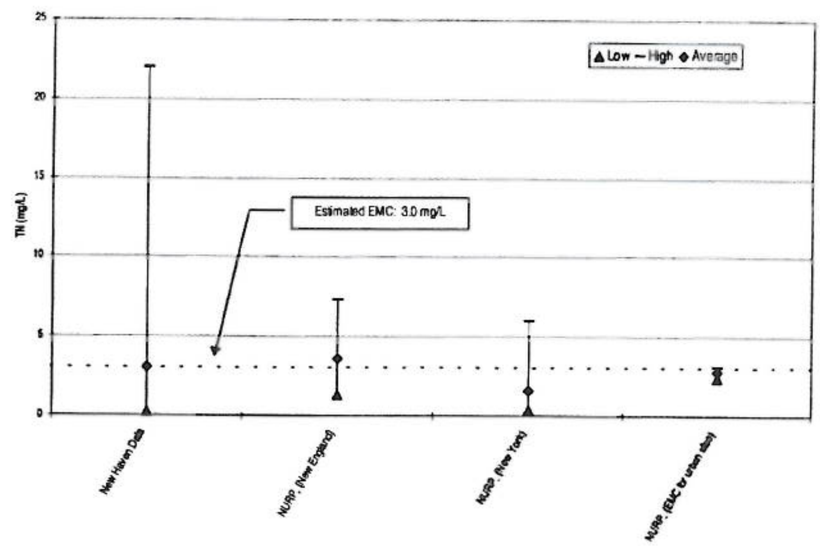


Figure 5-7
TN EMCs for Various Studies



Plant effluent quality is monitored in accordance with the discharge permit and applicable regulations. Effluent data from the WPCA's Daily Monitoring Reports (DMRs) for the dates of June 1, 1997 to May 31, 1998 were reviewed. This report presents six parameters: flow, TSS, BOD, fecal coliform, TN, and DO. Effluent quality requirements and the average effluent concentrations over this period are shown in Table 5-7. This data indicates that the plant is well within average monthly permit limits for TSS, BOD, and fecal coliform. Overall, of the influent treated, 99% of the effluent volume was within daily discharge permit limits for TSS, while 100% was compliant with respect to BOD and fecal coliform.

Flow

The average daily flow at the plant for the period of June, 1997 through May, 1998 ranged from 36.8 mgd to a maximum flow of 81.9 mgd. During wet-weather events, the plant may experience instances during the day in which the flow rate exceeds 60 mgd. In such cases, a wet-weather diversion is initiated. Diverted flows receive screening, grit removal, primary treatment, and disinfection prior to discharge to the harbor. The diversion volumes recorded during this period ranged from 0.04 to 21 MG with an event average of 2.8 MG. There were 41 instances over this period in which plant flows exceeded 60 mgd and a diversion flow was recorded.

There is a fair amount of correlation between rainfall and diversion flow in late winter and spring. In the drier months, there is significantly less correlation. A closer look at the data indicates that with significant rain events (> 0.5 inch), there was almost always diversion flow, but not necessarily on the same day. Likewise, except for a few unusual cases, there was no diversion flow without an associated storm. The degree to which effluent water quality is affected when wet weather flows exceed 60 mgd is presented in the following subsections. Appendix C provides detailed treatment plant water quality data.

TSS

TSS was sampled as a daily 24-hour composite sample. As summarized in Table 5-7, the average daily effluent concentration over the period sampled was 11.6 mg/L with a range of 3 to 121 mg/L. The plant therefore operates at 99% compliance with respect to TSS. During wet weather events, the interim permit limit of 90 mg/L applies. In two instances, the plant did not meet the interim permit's limit with respect to TSS for the period of data reviewed. For each of the days in which the TSS exceeded the interim maximum daily concentration of 90 mg/L, there was a recorded volume of diversion. Although there is no obvious correlation between the amount of diversion and TSS concentrations, the average TSS concentration for the days in which there was diversion flow was 22 mg/L, more than twice the yearly average.

BOD

As with TSS, BOD was sampled as a daily 24-hour composite sample. Average daily BOD concentrations were 8.1 mg/L, ranging from 3 to 77 mg/L. Since the instances in which flow concentrations exceeded 50 mg/L were during wet weather events, the interim permit applies. However, there were no instances in which the BOD_5 concentration exceeded the interim maximum daily limit of 90 mg/L, indicating that the treatment plant was in compliance 100% of the year. Again, each instance in which flows exceeded 50 mg/L, there was a rain event and an associated diversion flow. Although there does not seem to be a clear correlation between BOD_5 levels and volume of diversion, the average BOD concentration for diversion events were found to be 17.6 mg/L, over twice the yearly average.

TABLE 5-7
East Shore WPAF Performance Overview

Effluent Parameters	Average Daily Design Flow		June 1997 to June 1998 Effluent Performance Minimum	Average	Maximum
Total Flow (mgd)	40		26	37	82
Diversion Flow (mgd)[1]			0.04	2.8	21
	Permit Limits (October 24, 1995)				
TSS (mg/L)	Monthly Average	30/40[3]	9.3	11.6	15
	Daily Maximum	50/90[3]	3.0	11.6	121[6]
BOD (mg/L)[2]	Monthly Average	30/40[3]	5.7	8.1	12.6
	Daily Maximum	50/90[3]	3	8.1	77
Fecal Coliform (#/100 mL)	30-day geometric mean	200	2.18	5.8	15.5
	7-day geometric mean	400	1	8.1	109
TN (mg/L)	No limit[4]		4.3	9.3	17.1
DO (mg/L)	No limit[5]		3.1	5.0	8.2

[1] The maximum, minimum and average values are results taken from the days when there were recorded diversions.

[2] The discharge shall meet the more stringent of the average monthly concentration or monthly minimum removal efficiency requirements for each parameter (i.e., 85% removal of BOD and TSS or 75% removal during wet weather).

[3] Interim Limits applicable to wet weather flow require that the daily maximum concentration of BOD or TSS be no greater than 90 mg/L, with a monthly average concentration limit of 40 mg/L.

[4] There is no nitrogen limit other than no net increase from a 1991 base loading of 3,635 lb. In the near future there is to be an 8–10 mg/L 12-month rolling average limit.

[5] There is no limit for effluent. However, the State Water Quality Standard for SB/B waters is a minimum of 5.0 mg/L.

[6] The maximum value may have exceeded the interim permit limit as a result of wet weather flows combining with treatment units out of service for maintenance purposes.

Fecal Coliform

Fecal coliform is grab-sampled 12 times per month as the NPDES permit requires. Grab samples are to be taken during the day when the plant is operating at peak hourly flows. It is seen that the plant is easily within compliance year-round for both the 7-day geometric mean and the 30-day geometric mean.

TN

The recent upgrade of the secondary portion of the plant was designed to provide nitrogen removal. The average influent concentration is 29.5 mg/L. Primary treatment removes around 24% of the TN with its effluent concentration averaging around 22.5 mg/L; secondary treatment has a removal efficiency of around 59% with a final discharge concentration of 9.3 mg/L of TN. If a limit of 8-10 mg/L of TN is implemented by the State, some improvements may need to be considered.

Dissolved Oxygen

The average DO during the period from June 1, 1997 to May 31, 1998 is 5 mg/L, which meets the State standards for SB/B waters.

Selected EMCs for the East Shore WPAF

In order to quantify yearly loadings of the relevant pollutant parameters from the East Shore WPAF, EMCs must be specified. The EMCs chosen for the East Shore WPAF are simply the average concentrations based on the sampled data collected at the facility for the year from June 1, 1997 to May 31, 1998, as presented previously in this report and again in Table 5-8 below.

TABLE 5-8
EMCs Chosen for the East Shore WPAF

Parameter	BOD (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	Total Nitrogen (mg/L)
Event Mean Concentration	8.1	11.6	8.1	9.3

Note: For comparison, CSO EMCs are 75 mg/L (BOD), 150 mg/L (TSS), 1,000,000 MPN/100 mL (Fecal Coliform), and 21 mg/L (TN). Stormwater EMCs are 50 mg/L (BOD), 50 mg/L (TSS), 10,000 MPN/100 mL (Fecal Coliform), and 3 mg/L (TN).

Summary

A summary of the EMC inputs to the loading calculations is shown in Table 5-9. The EMCs remain constant for the design storms and annual simulation.

TABLE 5-9
Summary of Pollutant EMCs for Pollutant Loading Model Input

Pollutant Source	BOD (mg/L)	TSS (mg/L)	Fecal Coliform (MPN/100 mL)	TN (mg/L)
Quinnipiac River Inflow	3.5	56.5	1700	5.7
Mill River Inflow	3.1	15	130	0.3
West River Inflow	3.5	15	15	0.3
CSO	75	150	1,000,000	21
Stormwater	50	50	10,000	3
WPAF Effluent	8.1	11.6	8.1	9.3

Estimated Pollutant Loads

Methodology

To identify the most significant contributions to water quality impairments, a means of evaluating the relative contribution of each pollutant source is necessary. Mass loadings were used to quantify pollutant impacts. A mass load is defined as the total amount of contaminants (by mass) entering the river over a given period of time. Mathematically, this expression is written as:

$$Mass\ Load = EMC_{parameter}\ x\ Volume$$

The EMCs and discharge volumes for major pollutant sources were quantified previously in this report. The pollutant load calculations presented in this section are large-scale estimates based on approximations from the best available data to provide relative comparisons of pollutant loadings from a variety of sources.

Pollutant loads for BOD, TSS, FC, and TN have been calculated for the annual precipitation record and the 3-month and 2-year design storms for the following discharge sources in New Haven:

- River inflow (Quinnipiac, Mill, West, and New Haven Harbor)
- CSO
- Stormwater
- WPAF effluent

The following sections describe the relative contribution of each source. Pollutant loading conclusions are presented with respect to water quality standards (FC) and the other indicator parameters (BOD, TSS, and TN).

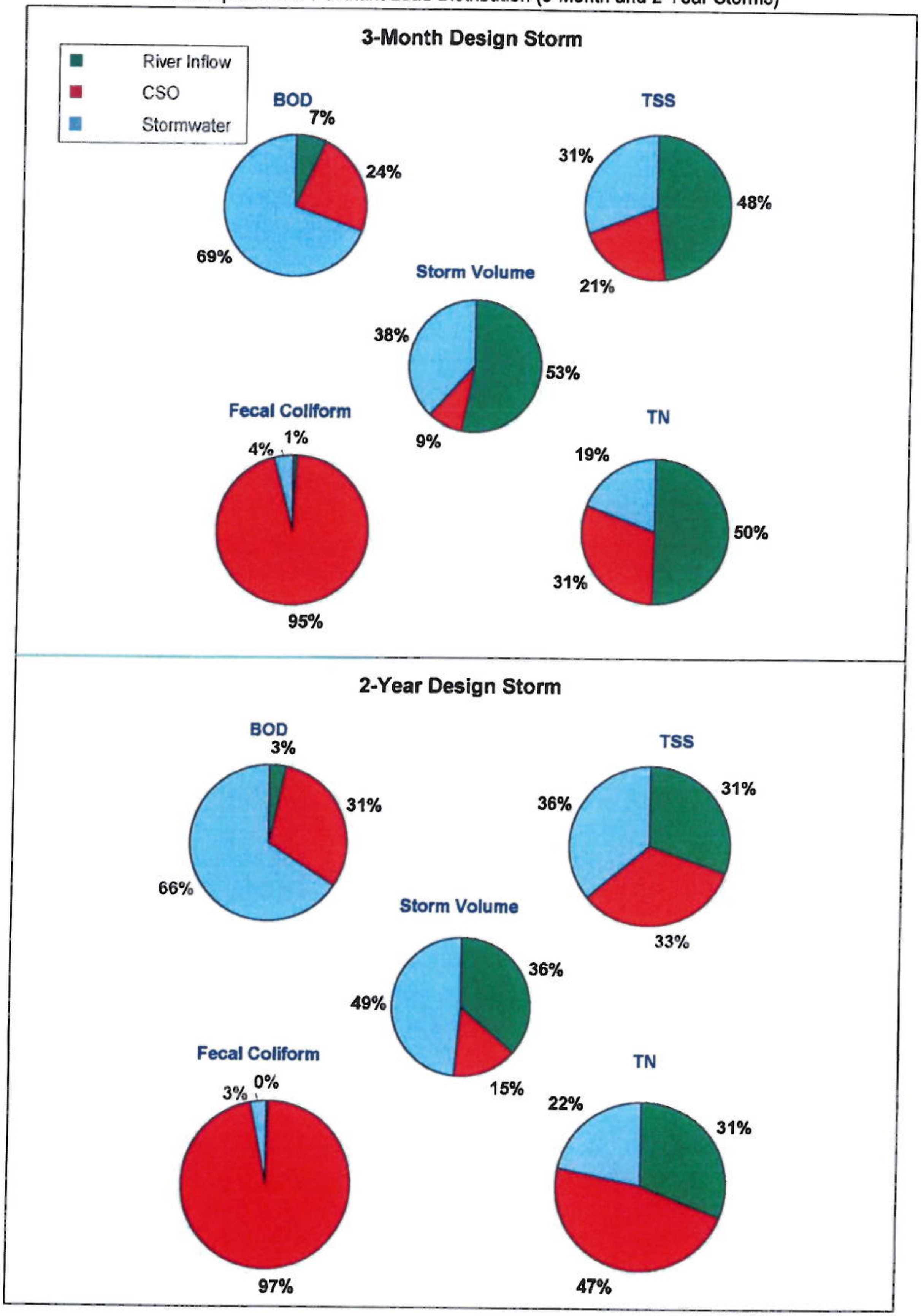
Loading Analysis

The pollutant loads for the 3-month and 2-year design storms and the annual precipitation record simulation are presented for each receiving water in the following subsections.

Quinnipiac River

Pollutant loads to the Quinnipiac River for the 3-month and 2-year design storms and the annual simulation are presented in Table 6-1. Pollutant load results from the 3-month and 2-year design storms indicate a significant impact from CSO and stormwater discharges. High fecal coliform loadings, as described previously in Section 3, are associated predominantly with CSO discharges, while BOD loadings are associated predominantly with stormwater discharges. Significant sources of TSS and TN loadings include upstream, CSO, and stormwater discharges. This is clearly supported by results of the design storm load analysis provided in Figure 6-1. (Since pollutant loads are similar for the 3-month and 2-year storms, the 3-month results will be presented only for the Quinnipiac River. For the other rivers and the harbor, the 2-year and annual results will still be presented.)

Figure 6-1
Quinnipiac River Pollutant Load Distribution (3-Month and 2-Year Storms)



Results of the annual simulation that the Quinnipiac River, prior to crossing the New Haven boundary, has high pollutant loads of BOD, TSS, and TN such that stormwater flows and combined sewer overflows do not significantly increase the total load to the river on an annual basis. The BOD, TSS, and TN loads from upstream sources equal 84%, 99%, and 99%, respectively, of the total load to the river as shown in Figure 6-2. One exception is the high fecal coliform load from CSOs to the river; CSOs represent 43% of the total fecal coliform load versus 53% from upstream sources.

TABLE 6-1
Pollutant Loads
Quinnipiac River

BIOCHEMICAL OXYGEN DEMAND (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	690	690	1,400,000
CSO	2,400	6,100	39,000
Stormwater	7,100	13,000	240,000

TOTAL SUSPENDED SOLIDS (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	11,000	11,000	22,000,000
CSO	4,900	12,000	78,000
Stormwater	7,100	13,000	240,000

FECAL COLIFORM (10^{12} MPN)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	1.5	1.5	3,000
CSO	150	370	2,400
Stormwater	6.4	12	220

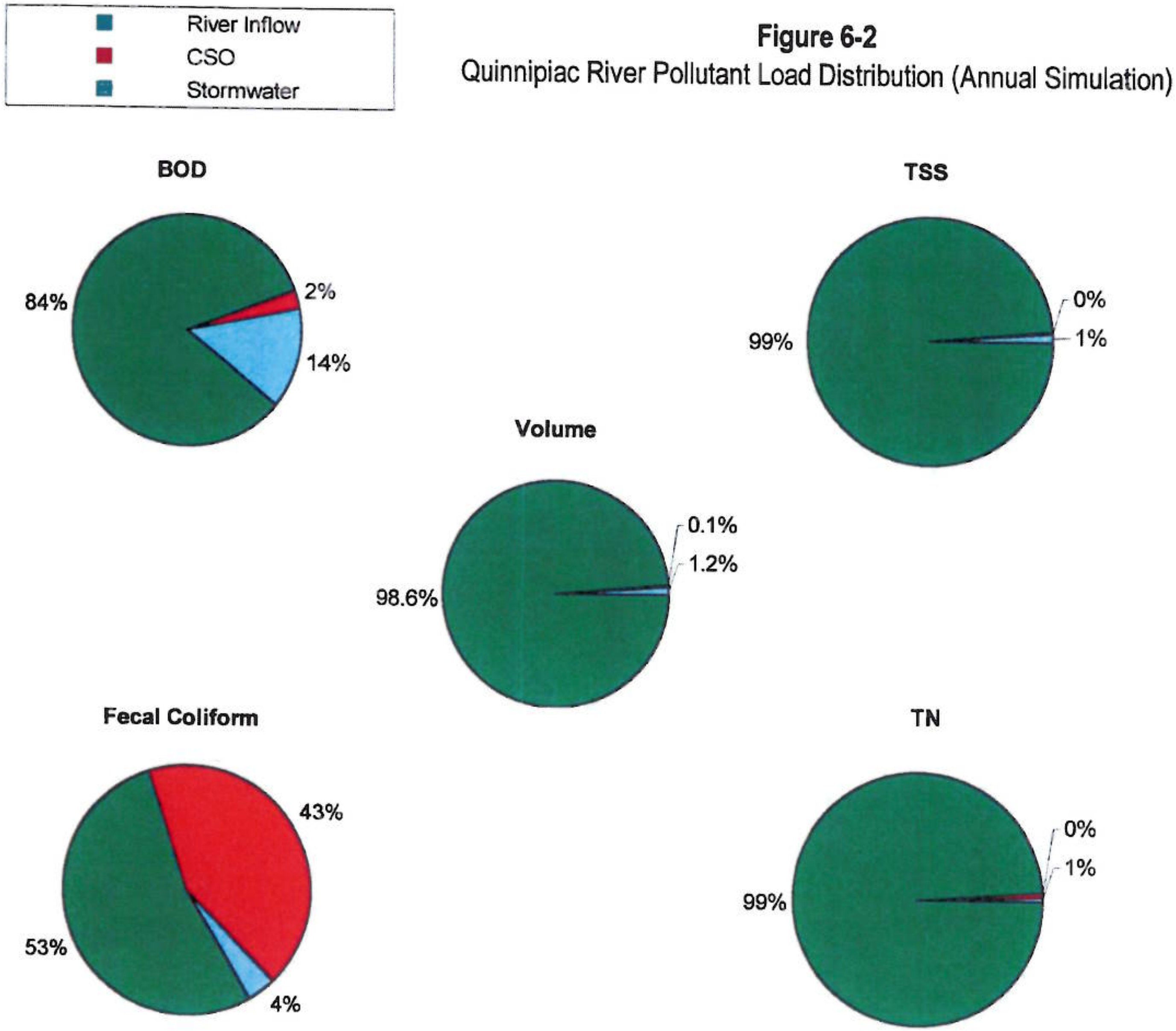
TOTAL NITROGEN (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	1,100	1,100	2,200,000
CSO	680	1,700	11,000
Stormwater	430	790	14,000

In summary, the review of historical data in Section 3, the discharge characterization results in Section 4, and the loading analysis in this section of the report supports the following conclusions for the Quinnipiac River within New Haven:

- Upstream sources deliver a significant pollutant load annually— the river regularly exceeds water quality standards
- Limited data indicate violations of FC standards during both dry and wet weather

Figure 6-2
Quinnipiac River Pollutant Load Distribution (Annual Simulation)



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- CSOs, particularly 016 and 015 which are a near popular fishing areas, are a significant source of FC during wet weather
- Elimination of CSOs will not likely bring the FC concentrations into compliance; control of other pollutant sources such as upstream and stormwater will likely be needed
- New Haven stormwater discharges are a significant source of BOD loads
- Upstream sources and New Haven sources both contribute significantly to TSS and TN loads during wet weather

Mill River

Pollutant loads to the Mill River for the 3-month and 2-year design storms and the annual simulation are presented in Table 6-2. Pollutant load results from the 3-month and 2-year design storms indicate a significant impact from CSO and stormwater discharges for all parameters. Loadings from upstream sources were minor for both storms. This is clearly shown in Figure 6-3.

Results of the annual precipitation analysis indicate that the Mill River, prior to crossing the New Haven boundary, has high pollutant loads of BOD, TSS, and TN such that stormwater flows and combined sewer overflows do not significantly increase the total load to the river on an annual basis. One exception is the high fecal coliform load from CSOs to the river (see Figure 6-4). Results of the annual precipitation analysis indicate that 72% of the BOD load is predominantly from upstream sources and is increased by more than 20% due to stormwater discharges. 92% of the TSS load and 69% of the TN load to the Mill River is from upstream sources. TN loads are increased by approximately 14% from CSOs and 17% from stormwater. CSOs contribute 87% of the FC load to the Mill River.

In summary, the review of historical data in Section 3, the discharge characterization results in Section 4, and the loading analysis in this section of the report supports the following conclusions for the Mill River within New Haven:

- Upstream waters (at Lake Whitney) meet most water quality standards; there are significant impacts from CSOs and urban stormwater downstream of the lake
- Limited data indicate violations of FC standards during both dry and wet weather
- CSOs, particularly 011, are the most significant pollutant source during wet weather
- CSO 012, although relatively small in volume and therefore load, is the most significant CSO in the more sensitive areas upstream of the tide gates
- Elimination of CSOs may not bring the FC concentrations into compliance; control of other pollutant sources such as upstream and particularly stormwater may also be needed
- Upstream sources and stormwater discharges deliver a significant BOD, TSS, and TN load annually; however, the pollutant concentrations and loads are substantially lower than those from upstream sources to the Quinnipiac River

Figure 6-3
Mill River Pollutant Load Distribution (2-Year Storm)

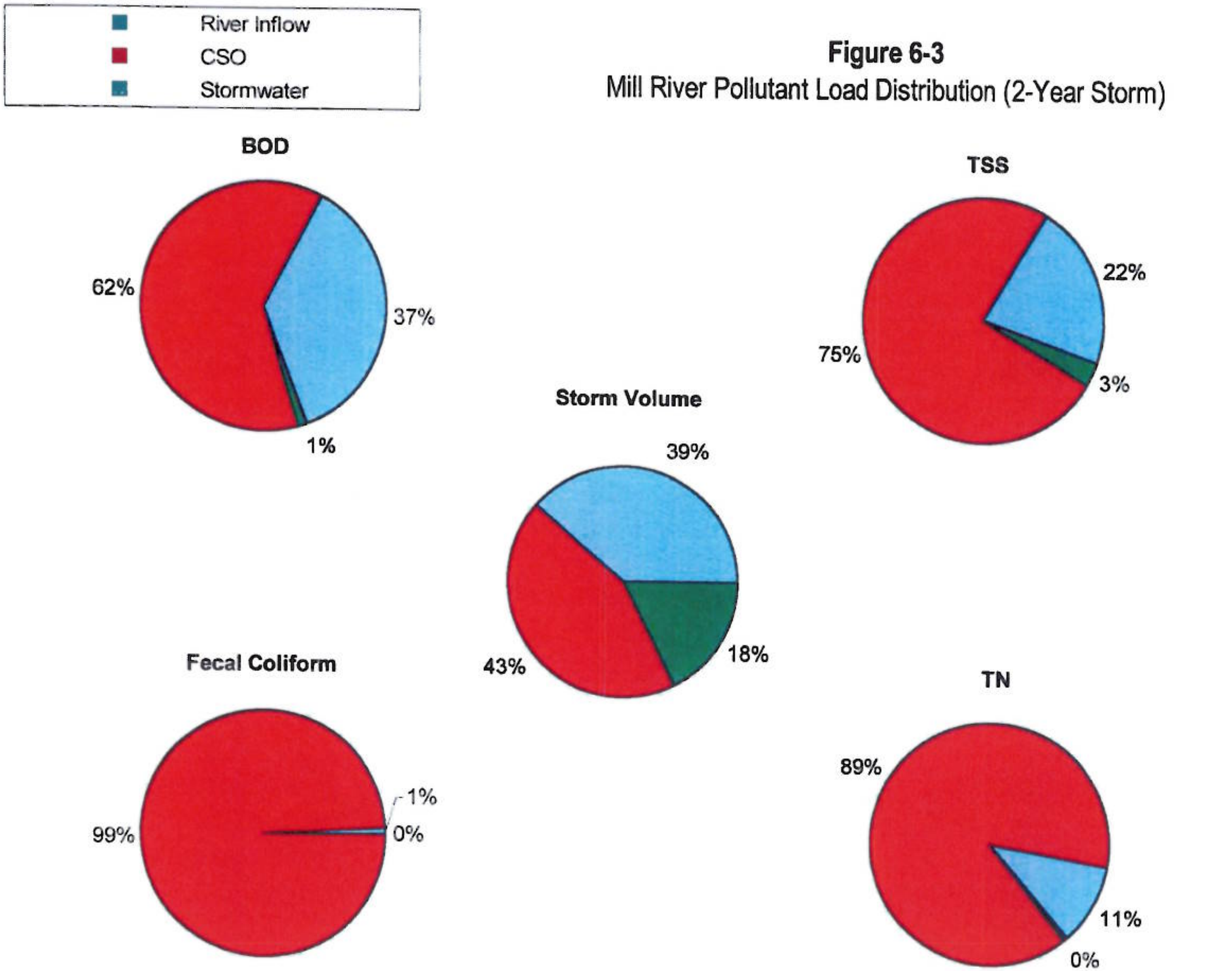


Figure 6-4
Mill River Pollutant Load Distribution (Annual Simulation)

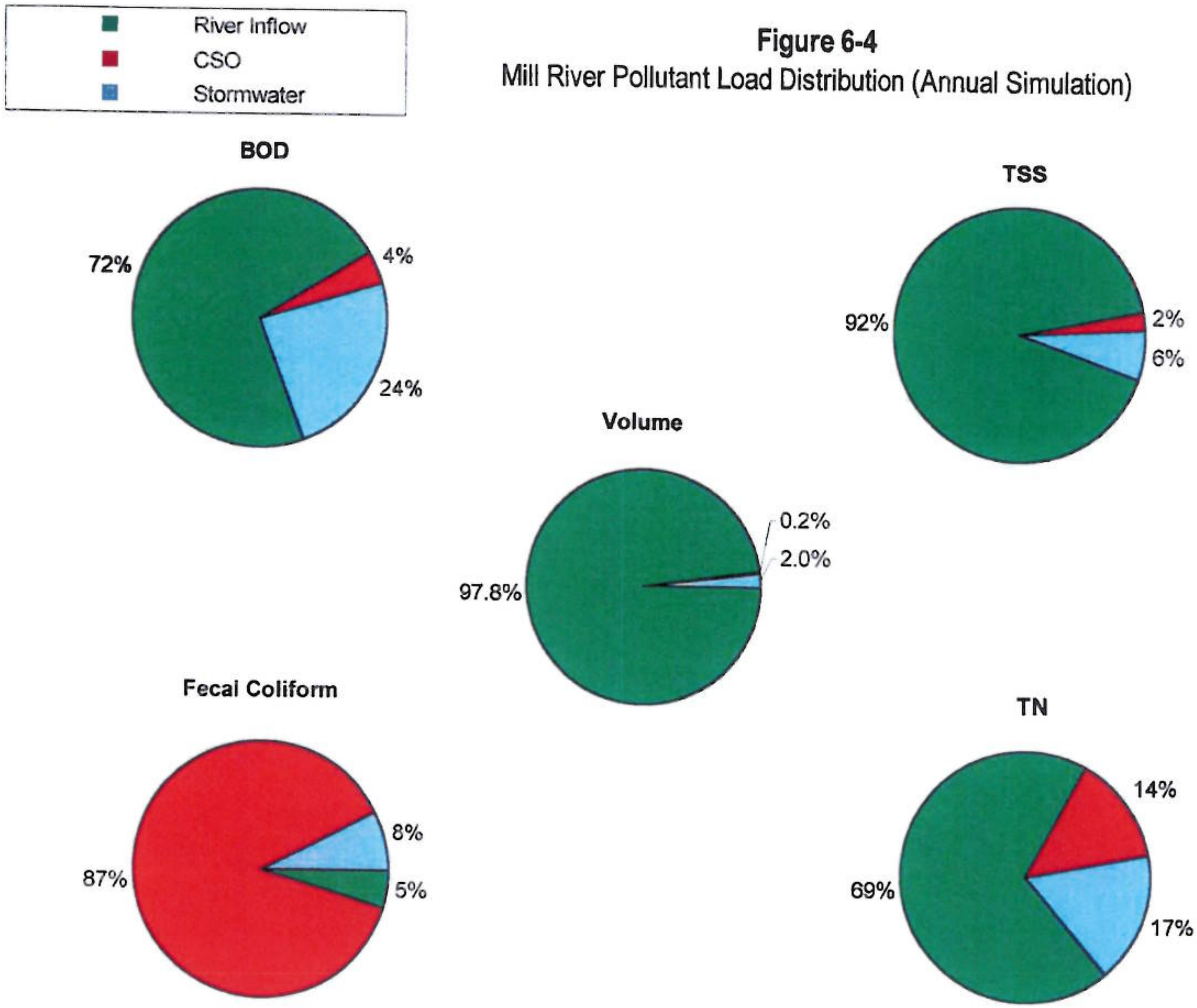


TABLE 6-2
Pollutant Loads
Mill River

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
BIOCHEMICAL OXYGEN DEMAND (pounds)			
River Inflow	180	180	390,000
CSO	3,600	11,000	23,000
Stormwater	3,500	6,600	130,000
TOTAL SUSPENDED SOLIDS (pounds)			
River Inflow	890	890	1,900,000
CSO	7,100	22,000	46,000
Stormwater	3,500	6,600	130,000
FECAL COLIFORM (10^{12} MPN)			
River Inflow	0.035	0.035	75
CSO	220	670	1,400
Stormwater	3.2	5.9	120
TOTAL NITROGEN (pounds)			
River Inflow	15	15	32,000
CSO	1,000	3,100	6,400
Stormwater	210	390	7,800

West River

Pollutant loads to the West River for the 3-month and 2-year design storms and the annual simulation are presented in Table 6-3. Pollutant load results from the 3-month and 2-year design storms indicate a significant impact from CSO and stormwater discharges for all parameters, except for FC which is predominantly from CSOs (see Figure 6-5). High fecal coliform and TN loadings are associated predominantly with CSO discharges, while high BOD loadings are associated predominantly with stormwater discharges. Significant sources of TSS include both CSO and stormwater discharges.

Results of the annual precipitation analysis indicate that the West River is significantly impacted by CSO and stormwater discharges. As shown in Figure 6-6, CSOs contribute 86% of the FC load and 24% of the TN load. Stormwater discharges account for almost 70%

Figure 6-5
West River Pollutant Load Distribution (2-Year Storm)

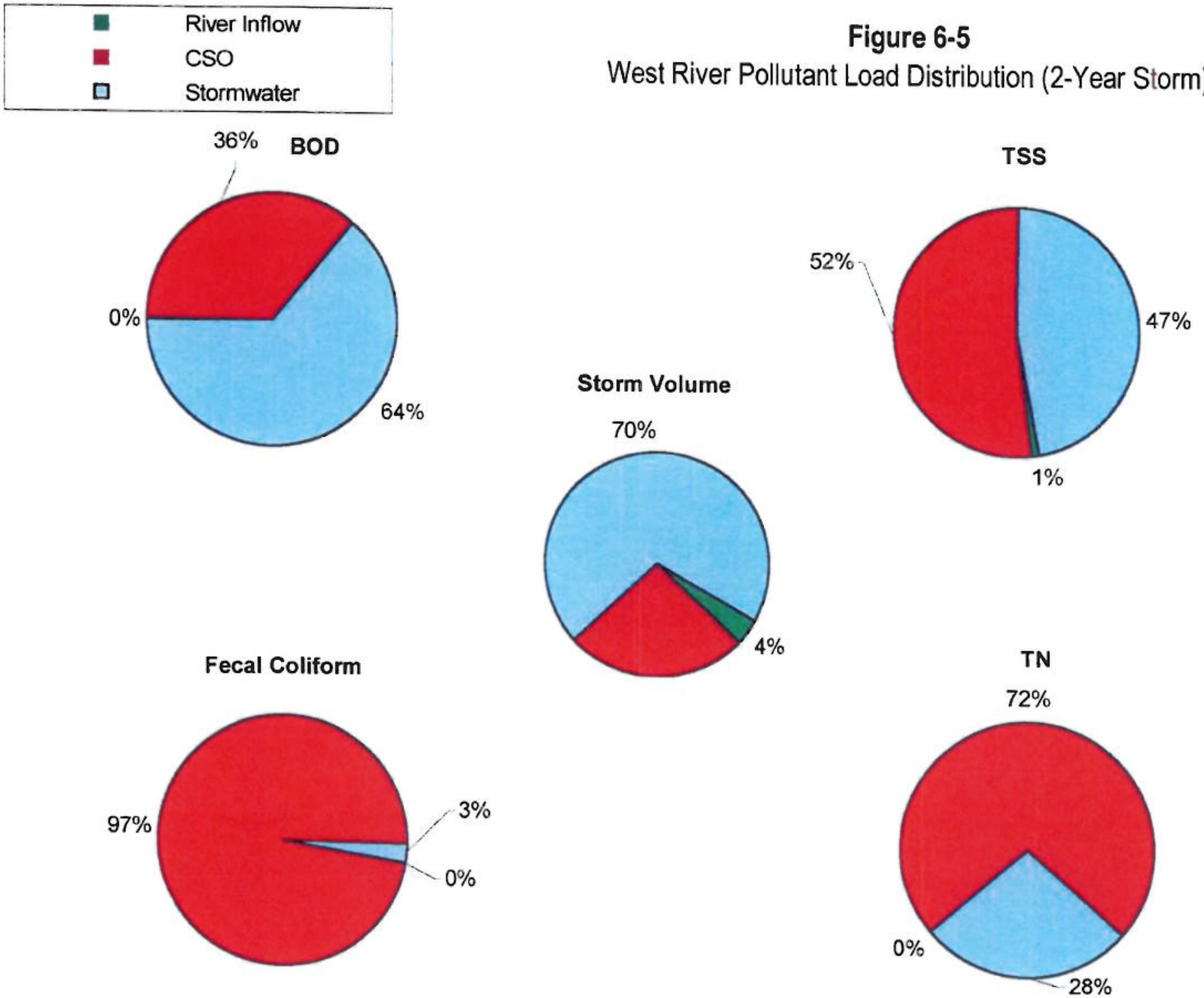
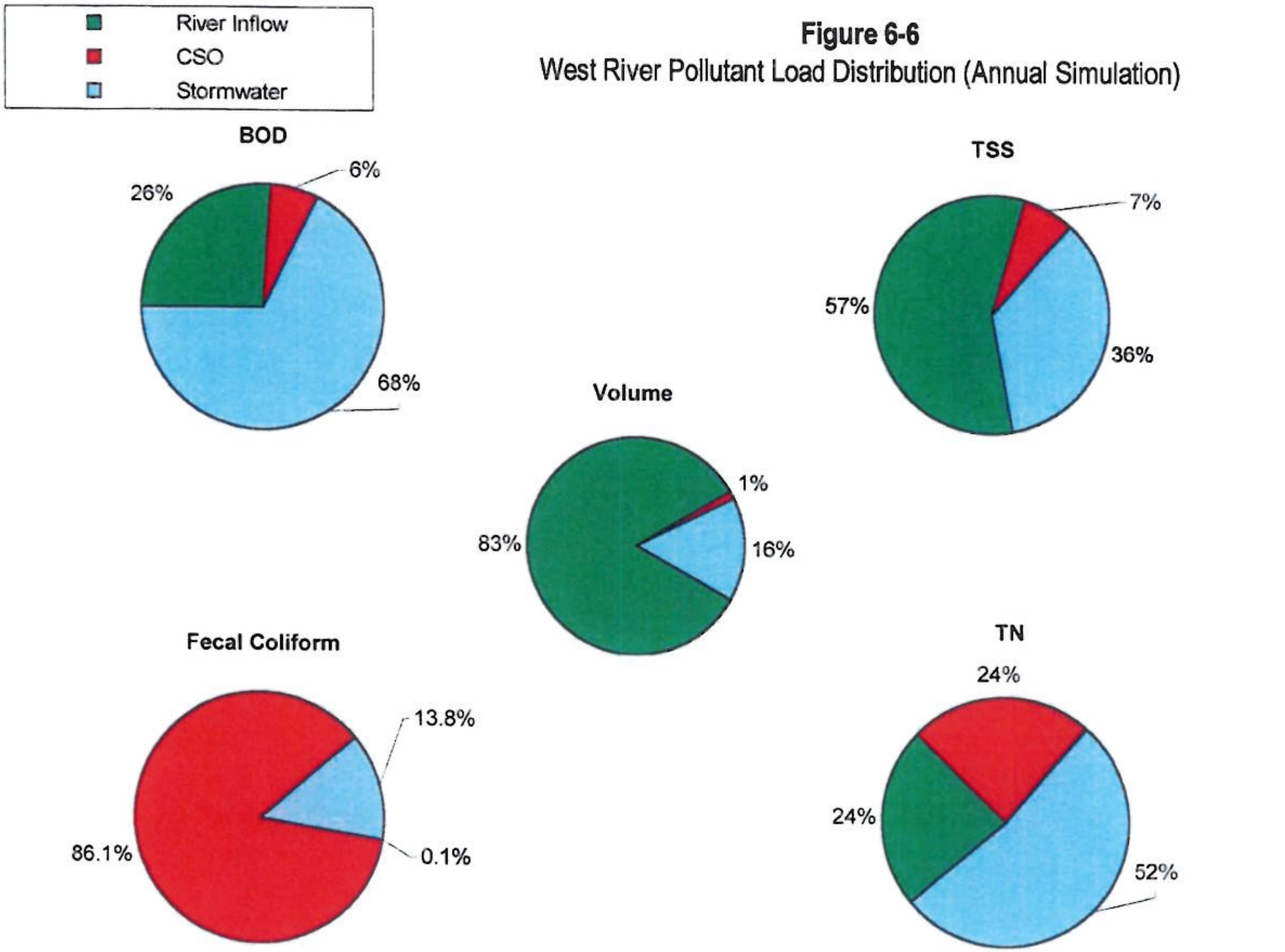


Figure 6-6
West River Pollutant Load Distribution (Annual Simulation)



of the BOD load, 36% of the TSS load, 14% of the FC load, and 52% of the TN load. 57% of the TSS load is from upstream sources.

TABLE 6-3
Pollutant Loads
West River (Includes Beaver Ponds)

BIOCHEMICAL OXYGEN DEMAND (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	84	84	200,000
CSO	4,200	13,000	50,000
Stormwater	14,000	24,000	520,000

TOTAL SUSPENDED SOLIDS (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	360	360	840,000
CSO	8,400	27,000	100,000
Stormwater	14,000	24,000	520,000

FECAL COLIFORM (10^{12} MPN)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	0.0016	0.0016	3.8
CSO	250	810	3,000
Stormwater	13	22	480

TOTAL NITROGEN (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	6.2	6.2	14,000
CSO	1,200	3,700	14,000
Stormwater	860	1,400	31,000

In summary, the review of historical data in Section 3, the discharge characterization results in Section 4, and the loading analysis in this section of the report supports the following conclusions for the West River within New Haven:

- Upstream waters are clean (meeting most water quality standards); there are significant impacts from CSOs and urban stormwater in New Haven
- Limited data indicate violations of FC standards during both dry and wet weather
- CSOs, particularly those located upstream of the tide gates in the most sensitive areas, are the most significant pollutant source during wet weather

- Elimination of CSOs may not bring the FC concentrations into compliance; control of other pollutant sources such as upstream and particularly stormwater may also be needed
- New Haven stormwater discharges deliver a significant BOD, TSS, and TN load during wet weather and annually

Pollutant loads to the Beaver Ponds for the 3-month and 2-year design storms and the annual simulation are presented in Table 6-4. There has been much interest in the water quality of the Beaver Ponds from New Haven Long-Term Control Plan stakeholder group. A separate study was recently completed (Diversified Technology Consultants June 1999) which highlights the significant negative impact from stormwater discharges. As can be seen from Table 6-4, the estimate of stormwater loads to Beaver Pond also highlights the significance of stormwater discharges for all water quality parameters analyzed. A minor impact from a single CSO also still remains.

TABLE 6-4
Pollutant Loads
Beaver Ponds

BIOCHEMICAL OXYGEN DEMAND (pounds)			
Source	**3-Month Design Storm**	**2-Year Design Storm**	**Annual Simulation**
CSO	0	130	13
Stormwater	3,700	6,200	140,000
TOTAL SUSPENDED SOLIDS (pounds)			
Source	**3-Month Design Storm**	**2-Year Design Storm**	**Annual Simulation**
CSO	0	250	25
Stormwater	3,700	6,200	140,000
FECAL COLIFORM (10^{12} MPN)			
Source	**3-Month Design Storm**	**2-Year Design Storm**	**Annual Simulation**
CSO	0	7.6	0.8
Stormwater	3.4	5.6	120
TOTAL NITROGEN (pounds)			
Source	**3-Month Design Storm**	**2-Year Design Storm**	**Annual Simulation**
CSO	0	35	4
Stormwater	220	370	8,000

New Haven Harbor

Pollutant loads to New Haven Harbor for the 3-month and 2-year design storms and the annual simulation are presented in Table 6-5. Pollutant loads indicate a significant impact from upstream sources for all parameters under all precipitation conditions, except for fecal coliform loads during individual storm events (see Figure 6-7). High fecal coliform loadings are associated predominantly with CSO discharges to the harbor and the Quinnipiac, Mill, and West Rivers. Significant sources of BOD, TSS, and TN loadings include both CSO and stormwater discharges, particularly BOD loads from stormwater.

Results of the annual precipitation analysis indicate that New Haven Harbor CSOs contribute 24% of the fecal coliform load. As shown in Figure 6-8, the WPAF contributes over 20% of the BOD load and 30% of the TN load to the harbor.

TABLE 6-5
Pollutant Loads
New Haven Harbor

BIOCHEMICAL OXYGEN DEMAND (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	36,000	75,000	3,000,000
CSO	3,700	8,200	57,000
Stormwater	11,000	20,000	400,000
WPAF	1,300	1,500	910,000

TOTAL SUSPENDED SOLIDS (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	58,000	120,000	26,000,000
CSO	7,400	16,000	110,000
Stormwater	11,000	20,000	400,000
WPAF	1,800	2,100	1,300,000

FECAL COLIFORM (10^{12} MPN)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	640	1,900	11,000
CSO	220	500	3,500
Stormwater	10	19	360
WPAF	0.01	0.01	4.1

TOTAL NITROGEN (pounds)

Source	3-Month Design Storm	2-Year Design Storm	Annual Simulation
River Inflow	5,500	12,000	2,300,000
CSO	1,000	2,300	16,000
Stormwater	670	1,200	24,000
WPAF	1,500	1,700	1,000,000

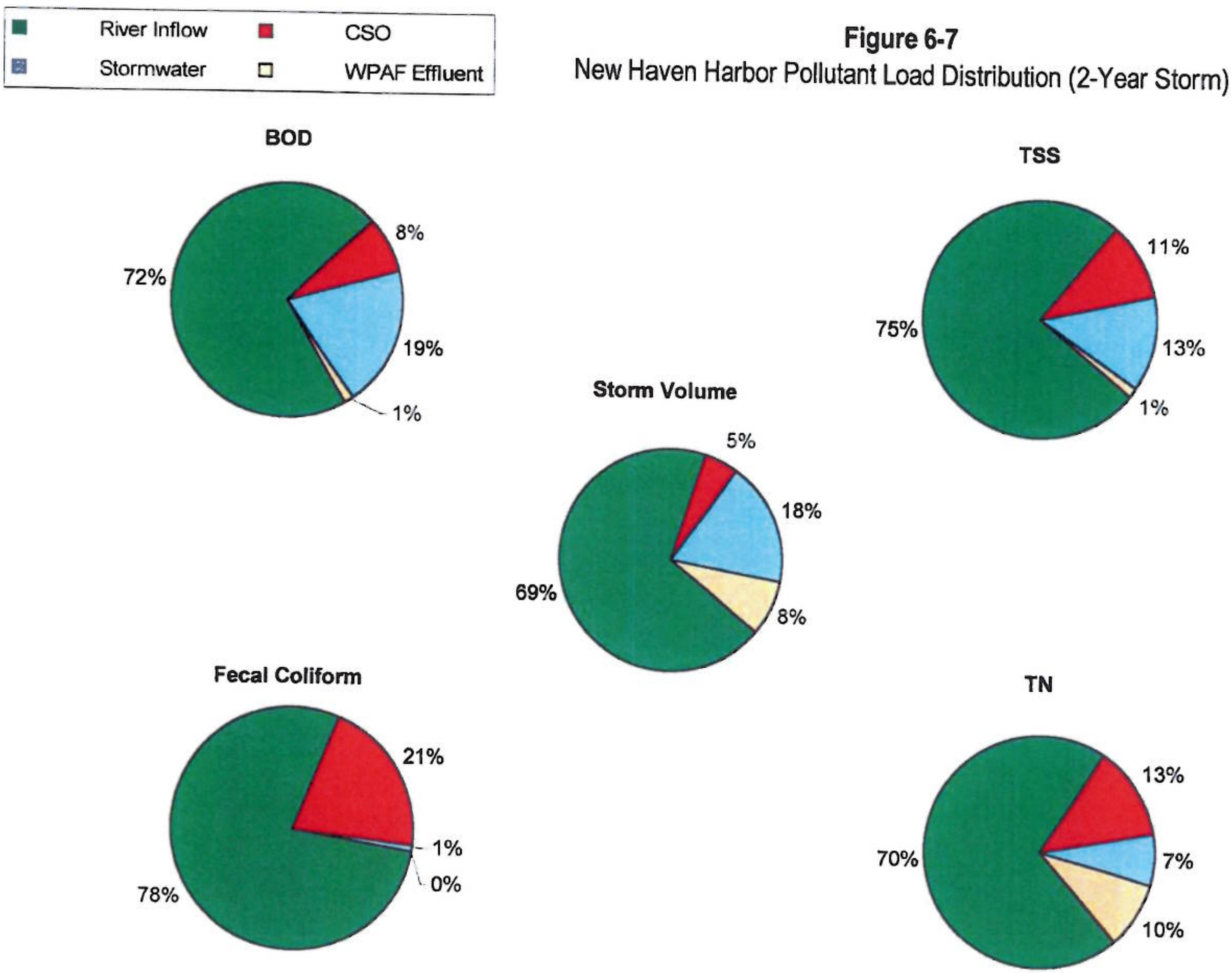
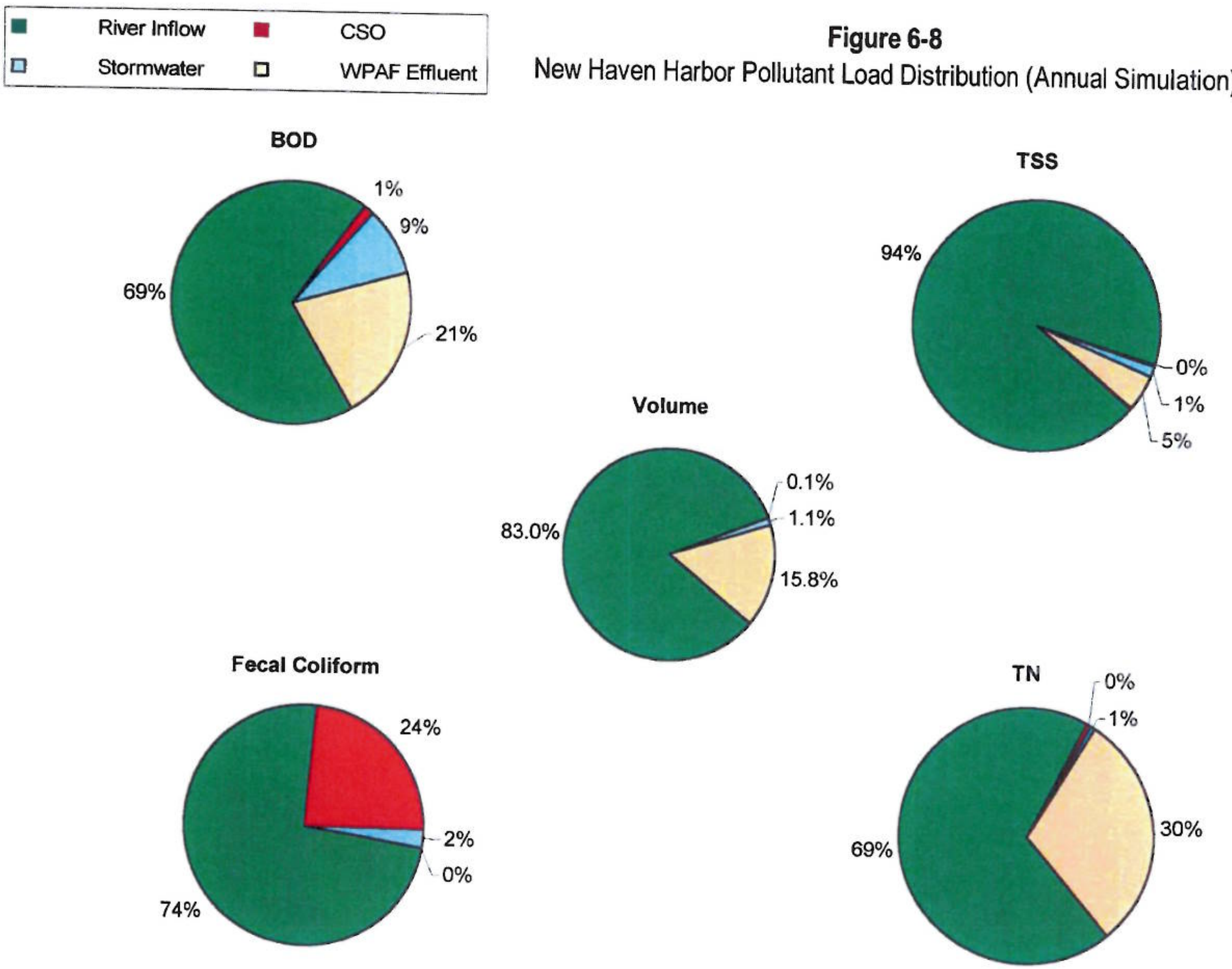


Figure 6-7
New Haven Harbor Pollutant Load Distribution (2-Year Storm)

Figure 6-8
New Haven Harbor Pollutant Load Distribution (Annual Simulation)



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In summary, the review of historical data in Section 3, the discharge characterization results in Section 4, and the loading analysis in this section of the report support the following conclusions for New Haven Harbor:

- Limited data indicate violations of FC standards during both dry and wet weather
- Upstream sources, particularly the Quinnipiac River, are the most significant pollutant sources during both dry and wet weather
- Elimination of CSOs may not bring the FC concentrations into compliance; control of other pollutant sources—particularly stormwater—may also be needed
- New Haven stormwater discharges deliver significant BOD and TSS loads during wet weather and annually
- Although the WPAF consistently meets permit limitations and provides a substantial pollutant load reduction (particularly for FC), the effluent delivers over 20% of the significant BOD load and 30% of the TN load to the harbor

Summary

On a per storm basis, the West River is the receiving water most impacted by New Haven CSOs and stormwater discharges, followed closely by New Haven Harbor with respect to stormwater discharges and small, frequent CSO discharges such as those from the 3-month storm. The Mill River is impacted less than the West River but more than the harbor by CSOs from less frequent, more intense storms such as the 2-year storm. Compared to the other receiving waters, the West River both receives the greatest load from CSOs and stormwater and has the smallest inflow volume and therefore the least dilution potential. Compared to the Mill and West Rivers, the Quinnipiac River is significantly impacted by upstream sources, particularly in both BOD and TN loads. Fecal coliform loads throughout the entire New Haven watershed are significantly increased by CSOs. BOD loads are significantly increased throughout the entire watershed by stormwater discharges. Water quality in Beaver Ponds is significantly impacted by stormwater discharges, and to a minor amount by a single CSO.

All pollutants that enter New Haven receiving waters eventually end up in the New Haven Harbor. On a design storm basis, the West River—as compared to the Mill and Quinnipiac Rivers—contributes the greatest pollutant load to New Haven Harbor for all parameters except TN, due primarily to wet weather discharges. For TN, the load from the Quinnipiac is slightly higher than that for the West River for the small, more frequent CSO events triggered by storms such as the 3-month storm. On an annual average basis, the Quinnipiac River—as compared to the Mill and West Rivers—contributes the greatest pollutant load to New Haven Harbor for all parameters, due primarily to upstream sources. Additionally, direct CSO discharges to the harbor contribute the greatest pollutant loads to New Haven receiving waters on an annual basis, followed closely by the CSOs on the West River. On an annual basis, direct stormwater discharges to the harbor and the WPAF effluent contribute sizeable BOD, TSS, and TN loads.

SECTION 7

CSO Ranking

For planning purposes and to balance the cost impacts of controlling CSO discharges over time, CSOs are often ranked from the highest priority CSOs requiring control to those of lesser priority. Although EPA CSO guidance documentation (USEPA 1995b) provides a formula to assist state regulatory agencies in ranking municipal CSO control programs across their jurisdiction , the criteria has a broad regional focus not a local perspective. For this reason, EPA CSO guidance suggests a review of locally-identified sensitive areas and uses, in addition to a thorough characterization of CSOs to assist in identifying CSO control priorities. As part of the New Haven CSO LTCP, a stakeholder group was formed in 1998 to provide direction in identifying sensitive areas and uses and CSO control objectives (CH2M HILL January 1999). The top ranked CSO control evaluation criteria included:

1. Meet State water quality standards
2. Protect critical areas
3. Eliminate dry weather overflows
4. Eliminate wet weather overflows (CSOs)
5. Maximize aquatic habitat

Section 6 provided a summary of the sources of water quality impairments for the various New Haven receiving waters. New Haven does not have the authority to control discharges from upstream sources into New Havens receiving waters; therefore, the City must focus on their own CSO and stormwater discharges. The West River was identified as being the receiving water most impacted by CSO discharges, followed by the Mill River, the Quinnipiac River, and New Haven Harbor; therefore, control of the New Haven CSOs should be ranked similarly. The goal of the New Haven CSO LTCP is to cost-effectively meet as many of the CSO control criteria as possible. It is important to note, however, that New Haven stormwater discharges are significant pollutant sources and may also require control before water quality standards can be met.

References

BETA/CH2M HILL Team. 1991. Combined Sewer Overflow Facilities Plan, Task 5 Technical Memorandum, *Pollutant Loads Summary*. October, 1991.

Camp Dresser & McKee Inc (CDM). 1996. *Stormwater EMCs for Urban Watershed Initiative.* Memorandum, December 3, 1996.

CDM. 1989. *Narragansett Bay Commission, CSO Study Area C.* Volume I, Engineering Report. January, 1989.

Cardinal Engineering Associates, Inc. 1981. *Facility Plan, Sewage Collection System*. Volume 1.

CH2M HILL. 1999. City of New Haven Long Term CSO Control Plan, Technical Memorandum #12, *Preliminary Evaluation of CSO Control Alternatives*. January, 1999.

CH2M HILL. 1998. City of New Haven Long Term CSO Control Plan, Technical Memorandum #3, *System Inventory and Model Results*. December, 1998.

CH2M HILL. 1998. City of New Haven Long Term CSO Control Plan, Technical Memorandum #7, *Nine Minimum Controls Report*. June, 1998.

CH2M HILL. 1997. City of New Haven Long Term CSO Control Plan, Technical Memorandum #2, *Database Design and System Modeling Approach*. July, 1997.

CH2M HILL. 1997. City of New Haven Long Term CSO Control Plan, Technical Memorandum #1, *Project Goals and Approach*. June, 1997.

CH2M HILL. 1992. *Stormwater Management Modeling for Narragansett Bay Commission CSO Facilities*. Volume I, Final Report. January, 1992. Studies conducted by O'Brien and Gere, Camp Dresser & McKee, and Greeley and Hansen.

CH2M HILL. 1991a. Bangor CSO Facilities Plan, Technical Memorandum #3, *Combined Sewer Sampling.*

CH2M HILL. 1991b. Bangor CSO Facilities Plan, Technical Memorandum #7, *CSO Loads and Water Quality Impacts*.

CH2M HILL. 1990. *CSO Facilities Plan*. Portland, Oregon.

CH2M HILL. 1989a. Combined Sewer Overflow Facilities Plan. Technical Memorandum 4-4/5-4, *Sewer System Modeling and Receiving Water Modeling for No-Action Alternative.* November 1989.

CH2M HILL. 1989b. Combined Sewer Overflow Facilities Plan, Volume II, Appendices. Technical Memorandum 3-10, *Monitoring Program Results and Analysis*. July 1989.

CH2M HILL and Dufresne-Henry, Inc. 1993. *Final Report, Combined Sewer Overflow Abatement Study, Master Plan,* City of Portland, Maine. December, 1993.

CH2M HILL and Dufresne-Henry, Inc. 1992. Portland CSO Abatement Study, Technical Memorandum No. 8, *CSO Pollutant Evaluation*. October, 1992.

Chapra, S.C. 1996. *Surface Water-Quality Modeling*. Preliminary Edition. New York: McGraw-Hill.

Connecticut Department of Agriculture, Bureau of Aquaculture (CT DA/BA). 1997. *1996 Annual Assessment of the Shellfish Growing Waters in the City of New Haven, CT*. Report by D.C. Bell and L. Romick. January, 1997.

CT DA/BA. 1990-1996. DA/BA Seawater Samples for Fecal Coliform Bacteria. Database printout. Obtained through personal communication.

Connecticut Department of Environmental Protection (CTDEP). No date. *Water Quality Standards*. Surface Water Quality Standards Effective May 15, 1992. Ground Water Quality Standards Effective April 12, 1996.

CTDEP. 1996. State of Connecticut Department of Environmental Protection *Stormwater Monitoring Report*. Hartford, CT: CTDEP.

CTDEP. 1995. NPDES Permit Modification for City of New Haven WPAF. October 24, 1995.

CTDEP. 1994. *State Water Quality Report* (305b Report).

CTDEP. 1991. *1991 Water Quality Assessment of Quinnipiac River*. Prepared by the Planning and Standards Division of CTDEP Water Management Bureau.

CTDEP. 1974. New Haven Harbor – Intensive Water Quality Survey.

Diversified Technology Consultants. 1999. *Feasibility Study, Beaver Ponds Park, for the City of New Haven*. DTC No. 98-275-101. June 1999.

EarthInfo, Inc. *EarthInfo NCDC Hourly Precipitation East*. CD-ROM. Boulder, CO: EarthInfo.

Frink, C.R. 1991. Estimating Nutrient Exports to Estuaries. *Journal of Environmental Quality* 20:717-724.

Greeley and Hansen. 1991. *The Narragansett Bay Commission, Combined Sewer Overflow Mitigation Study – CSO Area D*. Final Report, Volumes I and II. October, 1991.

Henderson, F.M. 1966. *Open Channel Flow*. New York: Macmillan Publishing Co.

Linsley, R.K., J.B. Franzini, D.L. Freyberg, and G. Tchobanoglous. 1992. *Water-Resources Engineering*. Fourth Edition. New York: McGraw-Hill.

Louis Berger & Associates. 1998. *Concept Design Report Amendment*. Narragansett Bay Commission Combined Sewer Overflow Abatement Program. April, 1998.

Louis Berger & Associates. 1993. *Concept Design Report*. NBC CSO Control Facilities Program.

Metcalf & Eddy (M&E). 1991. *New Haven Harbor, Summer 1990 Water Quality Monitoring Program, Final Report*. Project 89-117-41 for City of New Haven, CT. August, 1991.

M&E. 1986. *Report to the Narragansett Bay Commission, Providence, Rhode Island, on Combined Sewer Overflows in CSO Area A*. Volume I, Engineering Report. August 1986.

National Climatic Data Center (NCDC). 1998. Data obtained from http://www.ncdc.noaa.gov.

National Oceanic and Atmospheric Administration (NOAA). 1999. Data obtained from http://www.co-ops.nos.noaa.gov. Center for Operational Oceanographic Products and Services, National Ocean Service.

New Haven Parks Department (NHPD). No date (a). *Mill River Canoe Guide*, provided by a grant from The Women's Seaman's Friend Society.

NHPD. No date (b). *West River Canoe Guide*, provided by a grant from The Women's Seaman's Friend Society.

O'Brien & Gere. 1988. *Combined Sewer Overflow Mitigation Study, CSO Area B, Moshassuck River Interceptor Drainage Basin*, Final Report, Volumes I & II. Report to the Narragansett Bay Commission, Providence, Rhode Island. January, 1988.

The Quinnipiac River Fund. 1993. *Final Reports*. Administrated by The Community Foundation for Greater New Haven.

Schueler, T.R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Document No. 87703, Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, D.C. July, 1987.

South-Central Connecticut Regional Water Authority (SCCRWA). 2000. Data for TSS on Lake Whitney. Obtained by personal communication.

SCCRWA. 1999. *Lake Whitney Water Treatment Plant Environmental Evaluation*, SCCRWA Environmental Evaluation Team. January, 1999. New Haven, CT: SCCRWA.

SCCRWA. 1998. Data from Lake Whitney Rain Gauge. Obtained by personal communication.

United States Department of Commerce. 1955. *Rainfall Intensity-Duration-Frequency Curves For Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico.* Technical Paper No. 25. Hydrologic Services Division, Cooperative Studies Section. In cooperation with Corps of Engineers, U.S. Army and U.S. Department of Agriculture, Soil Conservation Service. Washington, D.C.: U.S. Government Printing Office.

United States Environmental Protection Agency (USEPA). 1995a. *Combined Sewer Overflows, Guidance for Long-Term Control Plan.* EPA/832-B-95-002. August, 1995. Washington, D.C.: USEPA.

USEPA. 1995b. *Combined Sewer Overflows, Guidance for Screening and Ranking.* EPA/832-B-95-004. August, 1995. Washington, D.C.: USEPA.

USEPA. 1994. *Long Island Sound Study.* Summary of the Comprehensive Conservation and Management Plan. July, 1994. EPA/842-S-94-001. Washington, D.C.: USEPA.

USEPA. 1983. *Results of the Nationwide Urban Runoff Program.* Volume I, Final Report. USEPA Water Planning Division. December, 1983. Washington, D.C.: USEPA.

USEPA. 1977. *Urban Storm Water Management and Technology Update and User's Guide.* Washington, D.C.: USEPA.

United States Geological Survey (USGS). 1984-1995. *Water Resources Data, Connecticut, Water Year 1984* to *Water Year 1995* (one report per year). USGS Water-Data Report CT-84-1 through CT-95-1.

University of Rhode Island. 1990. System Wide Modeling, Providence Area Combined Sewer Overflow Study. Spring 1990 Field Program. Department of Civil and Environmental Engineering. Kingston, Rhode Island: 1990.

Water Pollution Control Authority. 1994. Letter addressing appeal of NPDES Permit, dated October 28, 1994.

White, M. J., and R. E. White, Jr. 1997. *Eldridge Tide and Pilot Book, 1998*. Boston: White and White.

Yale University. 1998. School of Forestry and Environmental Sciences. Provisional data received through personal communication with S. Anisfeld, T. Trexler, M. Steinhoff, K. Bennett, G. Benoit, and P. Barten. Data from June 1, 1998 to September 28, 1998.

APPENDIX A

Selection of Design Storm Data

The New Haven MOUSE model was run with a series of design storms to characterize the behavior of the sewer system in storms of different volumes and intensities. This section describes the precipitation and tidal data that were used as boundary conditions in the MOUSE model for the design storm simulations. These data were input to the hydrologic model, which provided inputs to the hydraulic model representing wet weather inflow to the combined/sanitary sewer system. The hydraulic simulations then provided data that allowed the frequency, duration, and volume of CSOs to be calculated.

Precipitation

The characteristics of the design storms and the procedures used to develop them are described in this section. Four design storms were developed, with 3-month, 6-month, 1-year, and 2-year return periods. To derive these design storms, intensity-duration-frequency (IDF) curves were used.

To characterize rainfall data properly during the development of synthetic design storms, the data record must be of sufficient length and temporal resolution to determine the characteristics of the desired design storm. For example, to obtain an IDF curve that accurately reflects a 1-year recurrence interval, it is recommended that the data record be no shorter than 10 years. Otherwise, there may be significant statistical variation, subsequently decreasing confidence in the results. Likewise, to create a design storm with half-hour timesteps, a rainfall record with half-hour (or shorter) timesteps should be used. The precipitation data should have sufficient temporal resolution that the time of concentration[1] is greater than the rainfall data resolution. For a typical basin in New Haven, the time of concentration was calculated to be greater than 24 minutes. Hence, the rainfall data should have a timestep of less than or equal to 24 minutes.

The use of a recent data record is also recommended. The Department of Commerce's Technical Paper No. 25 (U.S. Dept. of Commerce 1955) includes IDF curves for both Hartford and New Haven. Data used to create the New Haven IDF curve were collected from 1909 to 1930, whereas the Hartford data were collected from 1905 to 1951. Although this paper is still used for designing storms, the data from which these curves draw may not be representative of current conditions.

A final critical characteristic is data integrity. Without data integrity, a rigorous statistical analysis of the precipitation data is prone to error. However, data sets rarely provide perfect data records, so sound judgment must be applied when choosing records to analyze.

Available data collected in and around the New Haven area were evaluated. Data sets were obtained from the following locations:

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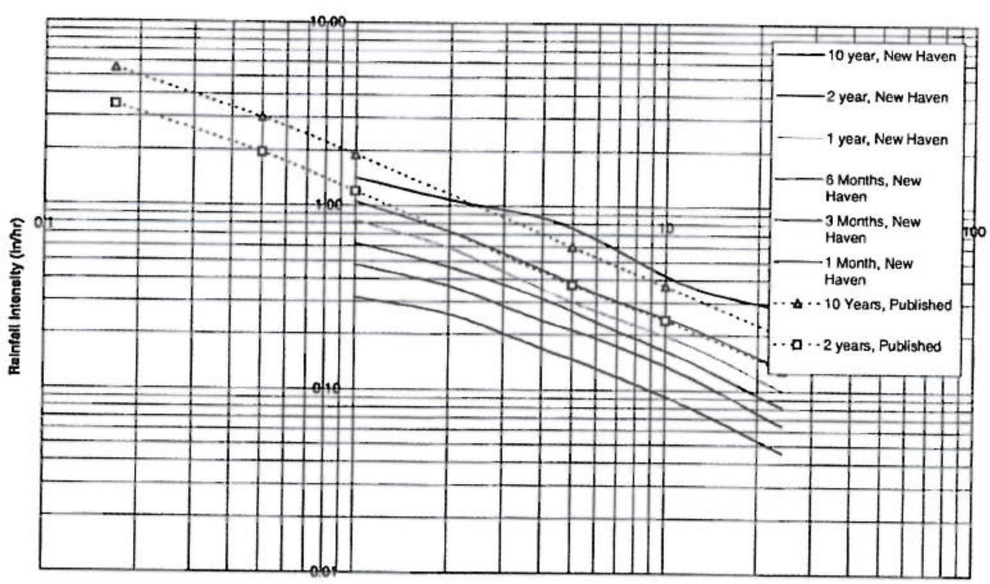
[1]The time of concentration is a hydrologic term referring to the time it takes runoff to travel across a typical basin from its farthest point to the outlet.

- **Tweed Airport in New Haven (1948–1969):** The data record provides hourly data spanning a 22-year period. The data set is complete and fairly lengthy, but the temporal resolution is only hourly.
- **The SCCRWA's Lake Whitney Gauge in New Haven (1912–1997):** The data record provides some data in 15-minute intervals, although it was collected only in the last few years; most of the data between 1912 and 1997 are at a daily timestep.
- **Bradley Airport in Hartford (1954–1994):** This data record is the most complete and comprehensive data set of the four. The data are in 1-hour increments and span 40 years.
- **The Bridgeport Airport in Bridgeport (1949–1996):** As discussed under "Selection of Average Annual Precipitation Data" below, the Bridgeport hourly record is missing has a significant amount of data.

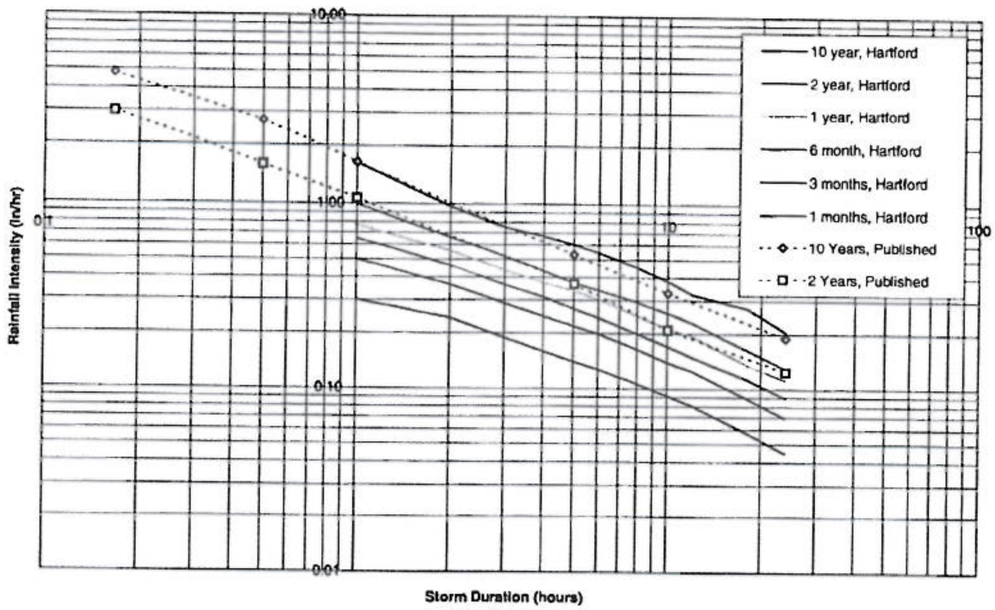
IDF curves were created using the Tweed Airport data. (The SCCRWA data was used to specify intensity and recurrence frequencies for storm durations of less than 1 hour.) The Tweed IDF curves were compared with the New Haven IDF curves reported in Technical Paper No. 25, as shown in Figure A-1. As seen in the figure, the data from Tweed Airport closely resembles data compiled for the 1955 publication. The resemblance is less pronounced for longer recurrence intervals, primarily due to the fact that a 22-year record is not sufficiently long to accurately produce an IDF curve at a 10-year recurrence interval.

FIGURE A-1
Comparison of New Haven IDF Curves and Published IDF Curves (TP No. 25, U.S. Dept. of Commerce 1955)



IDF curves were also generated for the Bradley Airport dataset and were compared with Hartford IDF curves reported in Technical Paper No. 25. The Hartford comparison is shown in Figure A-2. The curves compare closely. However, there are indications that recent rain records are more intense than records collected before 1950. There is a difference of about 8 percent between the intensities of the pre-1950 record and the post-1950 record. It is unclear as to whether this is a global trend or a change in data collection techniques.

FIGURE A-2
Comparison of Hartford IDF curves and published IDF curves (TP No. 25, U.S. Dept. of Commerce, 1955)



Because of the significant missing data in the Bridgeport data set, IDF curves were not generated using Bridgeport data.

The developed IDF curves for Hartford and New Haven are compared in Figure A-3. There does not seem to be much of a discrepancy between Hartford and New Haven. However, this similarity breaks down in recurrence intervals greater than 2 years due to the relatively short New Haven record (22 years). Barring any major shifts in climatology in the last 30 years, either data set should be sufficient for generating design storms in New Haven.

Since the published IDF curves do not have recurrence frequencies of less than 2 years, and available long data records do not have a temporal resolution shorter than 1 hour, IDF curves that incorporate storms with durations less than one hour and return intervals shorter than 2 years were estimated using best available resources. The data used to specify the part of the IDF curve that covers storms with durations 1 hour or greater is the Tweed Airport record. Although this record is fairly old, any discrepancy in intensities due to recent shifts in climatology will be masked by the use of a number of design storms that span a number of different recurrence frequencies. To specify the part of the IDF curves with durations less than 1 hour, intensities were extrapolated from both the published IDF curves and the generated IDF curves and then verified using the limited SCCRWA data record. The resulting IDF curve with SCCRWA data superimposed is shown in Figure A-3.

FIGURE A-3
Comparison of New Haven and Hartford IDF Curves. Curves were created using the New Haven Tweed record (1948–1969) and the Hartford record (1954–1994)

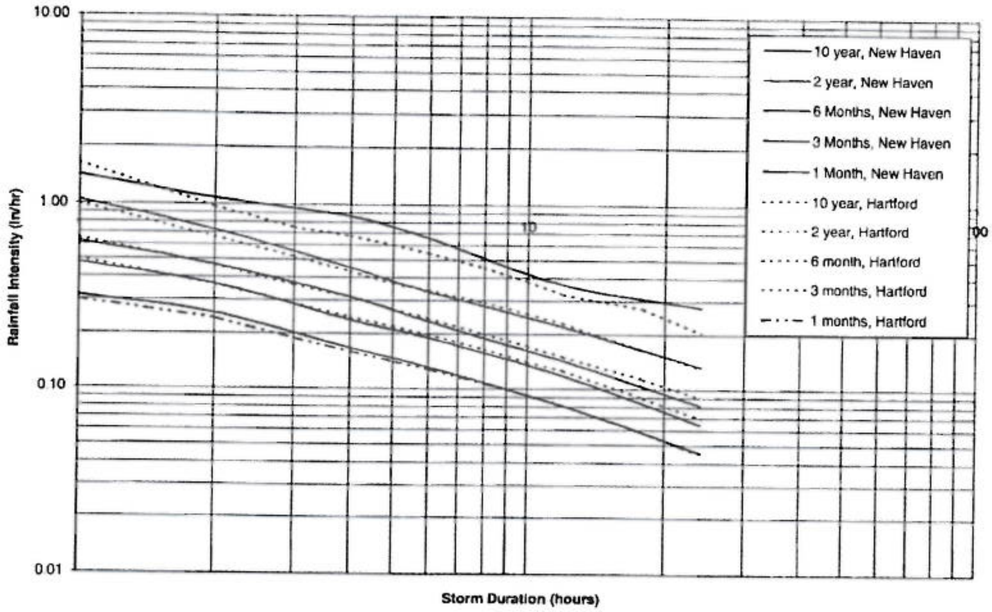
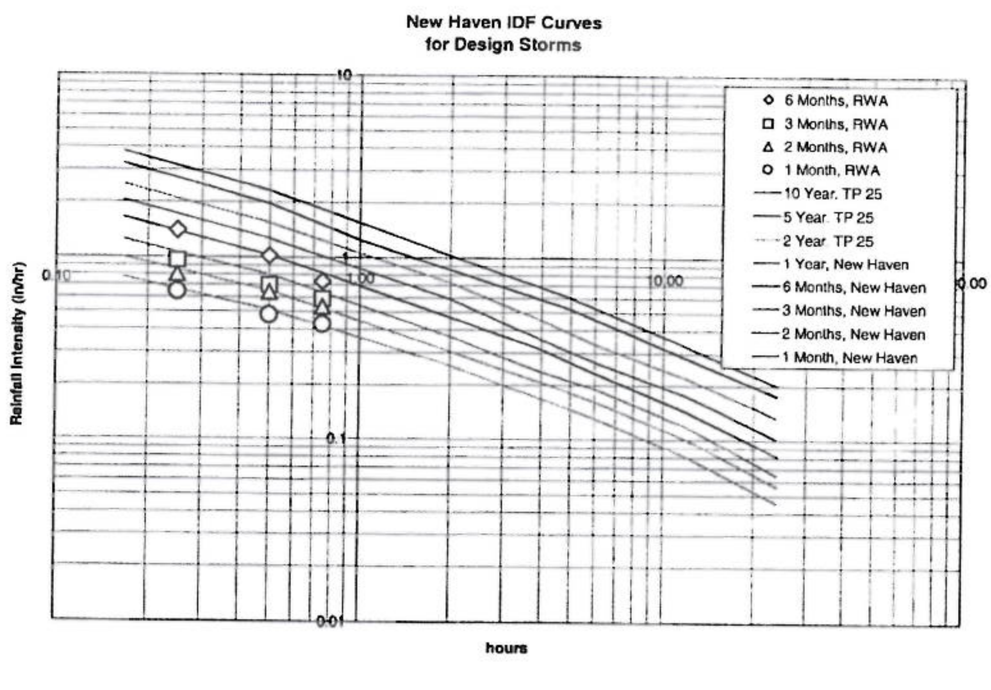


FIGURE A-4
IDF Curves for New Haven. This set of curves was used to create synthetic design storms.



Design Storms

With the IDF curves for New Haven established, the derivation of representative storm events was possible. The IDF curves shown in Figure A-4 were used to generate the design storms.

It was first necessary to determine the distribution of rainfall intensities with time; for example, the point in a storm event when the most intense rainfall is likely to occur. It was determined in a study in Providence, Rhode Island, that the peak intensity in a storm event would occur (on average) about 60 percent through its duration (Metcalf and Eddy 1986). For New Haven, it was likewise assumed that the peak occurs later through its duration.

To construct a synthetic storm, rainfall depths for various storm durations are extracted from the IDF curves. The peak depth is plotted at its appropriate time through the storm's duration. Then, for each extracted depth in order of increasing duration, the amount of rainfall already plotted is subtracted from each extracted depth. The remaining rainfall in each increment is calculated as an average intensity and plotted as intensity versus time, centered around the peak. Summing incremental areas from the start of the synthetic storm to its end produces a total storm depth equivalent to the total storm depth obtained from the IDF curve for that recurrence interval and storm duration.

Design storms that have 3-month, 6-month, 1-year, and 2-year recurrences were constructed using this technique. The intensities are tabulated in Table A-1. Intensities during the peak of each storm were calculated using a 15-minute timestep to account for the short time of concentration of 24 minutes noted earlier.

TABLE A-1
Design Storm Characteristics

	Design Storm Intensities (in/hr)			
Duration (hr)	**3-Month**	**6-Month**	**1-Year**	**2-Year**
1	0.07	0.08	0.08	0.12
2	0.11	0.12	0.10	0.13
3	0.12	0.17	0.13	0.21
3.25	0.27	0.40	0.52	0.50
3.5	0.55	0.60	0.66	0.93
3.75	1.05	1.40	1.65	2.15
4	0.28	0.40	0.62	0.82
5	0.18	0.23	0.34	0.34
6	0.09	0.08	0.10	0.15

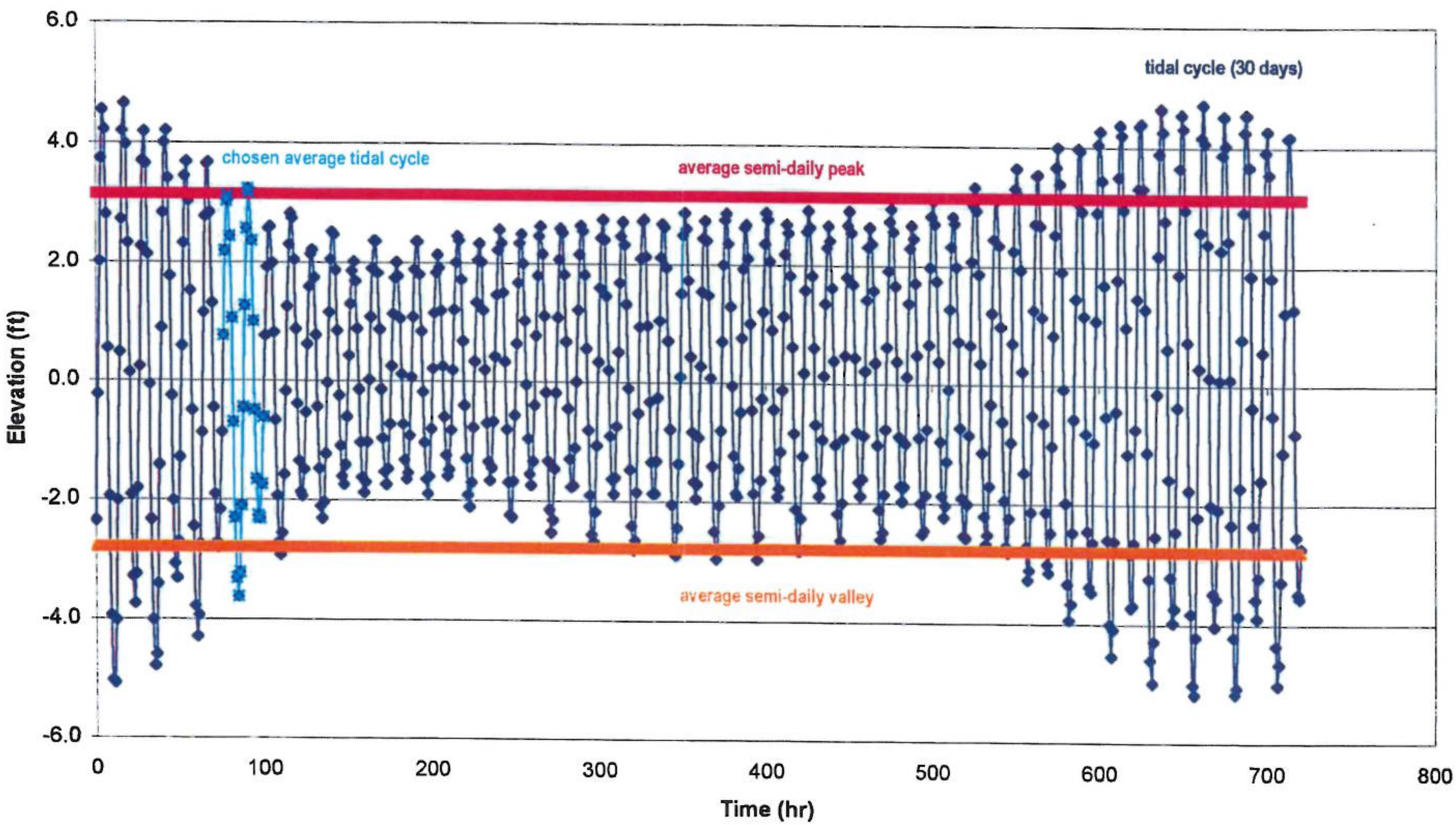
Tides

Several outfalls and regulators in the New Haven sewer system are at elevations low enough to be affected by tidal waters. High receiving water surface elevations at sewer outlets can delay overflows or cause them to occur in different locations due to backwater when tide gates are closed during high tides. In some cases, the lack of a tide gate or a non-functioning or partially functioning tide gate may allow tidal inflow to the sewer system. Therefore, the water surface elevations during any period of time simulated are used in the model as boundary conditions.

Since tidal extremes vary, an average tidal cycle was chosen for use in the design storm simulations. This choice, when combined with rainfall of a certain return period, provides a probability of similar return occurrences to that desired for the rainfall. The harmonic constants for the tides measured at Bridgeport, CT, were obtained from the NOAA website (1999). The amplitudes were adjusted for the offset between New Haven and Bridgeport as found in the *Eldridge Tide and Pilot Book, 1998* (White and White 1997). The harmonic constants were used to develop a full lunar tidal cycle, as shown by the dark blue line in Figure A-5. Because an average cycle is needed, the average values of the semi-daily peaks and valleys were calculated (shown by the pink and orange lines, respectively). A day-long cycle that approximated average amplitudes was then selected (light blue line).

The tidal cycle was adjusted in time so that its peak would occur at approximately the same time that the peak rainfall intensity was occurring. This superposition provides a conservative condition for evaluating the wet weather impacts from the design storms.

Figure A-5
Average Tidal Cycle for New Haven
Developed from Harmonic Constants Obtained from NOAA



bridgetides.xls

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APPENDIX B

Selection of Average Year Data

The hydraulic characterization includes an assessment of the sewer system and CSO performance for a 12-month period under average rainfall conditions. Rainfall data from the representative year were used in an annual simulation by the model to determine the number of overflow events and related pollutant loading to receiving waters. Simulation of individual storm events, which is performed to meet different goals, does not include the cumulative impacts from multiple storm events upon the sewer system and receiving waters. The simulation of a year that approximates average conditions does incorporate these effects. It was necessary, therefore, to obtain, review, and perform statistical evaluations of available precipitation data so that a representative year could be selected.

To perform the analysis, the following statistics were examined:

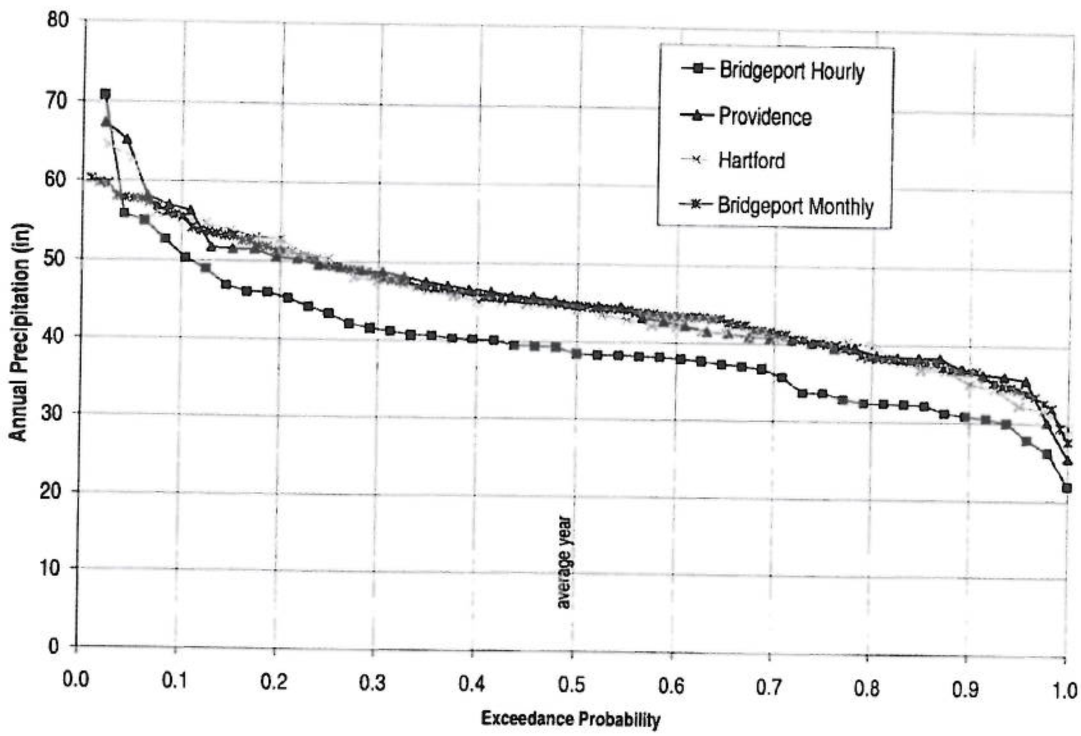
- Annual precipitation
- Monthly precipitation
- Number of storm events
- Maximum event volume
- Maximum event intensity

Through analysis of flow data from the East Shore WPAF, it was determined that during most storms, the sewer system returned to normal dry weather flow within 6 hours of the end of rainfall. Therefore, for this analysis a storm event was defined as a period of rain that was separated from other periods of rain by at least 6 hours of dry weather.

Evaluation of Available Data Sets

To determine the average rainfall year, it is best to use a long-term rainfall record to minimize the effects of extremely dry or wet periods. In addition, to assess the characteristics of individual storm events, it is necessary to have data at a minimum of hourly increments. One difficulty in performing an analysis such as this one is that data sets are often not complete and are sometimes of questionable quality. As a picture of variability between data sets, Figure B-1 shows the annual precipitation totals taken from data sets in Hartford, CT, Providence, RI, and Bridgeport, CT. Annual totals for Bridgeport derived from both monthly and hourly data sets are included. The annual precipitation values in Figure B-1 are graphed against the probability of each value being exceeded. As long as all the data sets span a sufficient number of years, the lines should lie on top of each other, showing that the expected values for annual total precipitation is similar between the three cities. However, Figure B-1 shows that the Bridgeport hourly data set has noticeably lower annual totals than the other data sets, suggesting that it is missing data.

FIGURE B-1
Annual Precipitation Records for New Haven, Hartford, Providence, and Bridgeport (monthly and hourly data sets)



Rainfall data from Tweed Airport in New Haven were selected to determine which year best represents average conditions for a 12-month period. However, because of concern about the short length of the hourly rainfall record (22 years), an analysis was also performed for data from Hartford. Further concern arose because the Tweed and Hartford data encompassed several drought years and the Tweed data were not recent, so another analysis was performed for Bridgeport, and comparisons with data from Providence were made. Annual rainfall from Lake Whitney was also used during the analysis. Table B-1 summarizes the data sets along with the concerns and sources for each. The presentation in this section of the analysis to determine a representative 12-month period focuses on New Haven data, but the questions about individual data sets will also be addressed.

Annual Precipitation

Annual precipitation totals at New Haven's Tweed Airport Gauge and the related average over the 22-year period were calculated. Six years during which total annual precipitation was within about 4.4 percent of the average were then selected for further analysis. Table B-2 lists the years and annual precipitation depths. Figure B-2 shows the annual precipitation volumes graphed against the probability that a given depth of precipitation will be exceeded in a given year, in order of decreasing precipitation volume. The 6 years selected are highlighted in the figure. Annual precipitation depths in the 22-year record varied from 27.69 to 53.78 inches, with an average of 41.27 inches.

TABLE B-1
Summary of Data Sets Employed in the Analysis

Location	Dates	Data Concerns	Source
New Haven – Tweed Airport	1948–1969	Encompasses drought period; not recent; not lengthy	EarthInfo
Hartford – Bradley Airport	1954–1994	Different rainfall intensities than New Haven; encompasses drought period	EarthInfo
Bridgeport Airport (monthly data)	1804–1820, 1873–1970, 1981–1983	Hourly data are required for full analysis; encompasses drought period	NCDC Website
Bridgeport Airport (hourly data)	1949–1996	Significant holes exist in data set; encompasses drought period	EarthInfo
Providence – Green Airport	1948–1994	Distance from New Haven; encompasses drought period	EarthInfo
New Haven - Lake Whitney (annual data)	1912–1997	Hourly data are required for full analysis; encompasses drought period	Regional Water Authority

TABLE B-2
Six Average Years According to Annual Precipitation Volume at New Haven's Tweed Airport

Year	Annual Precipitation Volume (in)
1950	39.47
1959	43.08
1960	41.65
1961	41.18
1967	40.63
1968	40.11
22-Year Average	**41.27**

Monthly Precipitation

Once 6 years with average annual precipitation depths had been selected, the monthly depths during each of the years were examined to see if there were any extremely wet or dry months that would not be representative of average conditions. Table B-3 shows the monthly totals for each year and the average monthly precipitation depth for the 22-year record. Monthly values that differ by 60 percent or more from the average value are shaded. The table shows that monthly precipitation during 1968 varied often from the long-term monthly averages, with 5 months differing by more than 60 percent from the average. That year was abnormally wet in November, December, and June and abnormally dry in April and July. Use of a year such as 1968 could affect the analysis of seasonal pollutant loads and the estimate of related impacts to uses in the receiving waters (e.g., swimming).

FIGURE B-2
Annual Precipitation Depth versus Exceedance Probability for Analysis Period at New Haven's Tweed Airport
(6 average years selected are shown by dark circles)

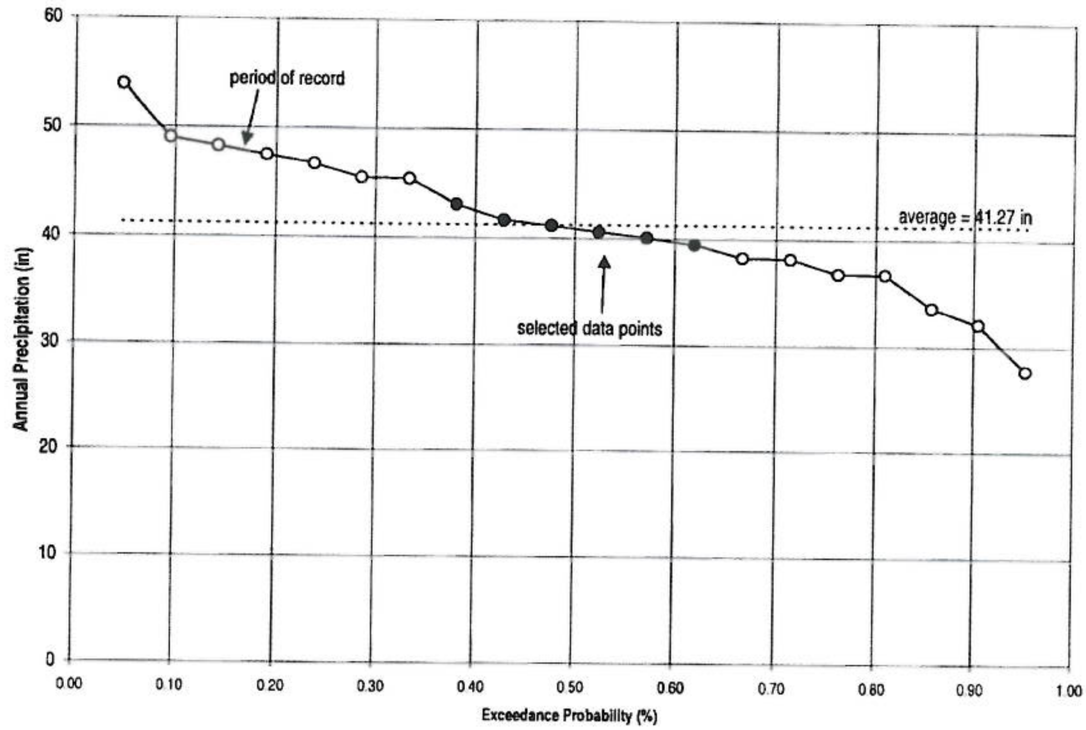


TABLE B-3
Monthly Precipitation Depths in New Haven (inches)

	1950	1959	1960	1961	1967	1968	Average
Jan	3.31	2.53	2.41	2.23	1.40	1.92	3.27
Feb	3.61	2.50	4.27	3.28	2.87	1.49	3.27
Mar	2.93	4.32	2.46	3.77	5.35	4.58	3.86
Apr	2.40	3.88	2.90	5.59	3.26	1.56	3.86
May	3.65	1.18	3.16	6.00	5.75	4.48	3.64
Jun	3.61	4.88	2.42	2.37	2.23	4.52	2.46
Jul	3.83	4.04	6.08	2.32	4.17	1.12	3.01
Aug	5.64	3.31	2.06	3.54	3.25	3.02	3.60
Sep	1.09	0.64	7.73	4.06	1.09	2.34	2.97
Oct	1.70	7.42	2.69	2.13	2.45	1.92	3.34
Nov	3.10	3.90	2.52	2.60	3.50	6.56	4.01
Dec	4.60	4.48	2.95	3.29	5.31	6.60	4.05
Total	**39.47**	**43.08**	**41.65**	**41.18**	**40.63**	**40.11**	**41.33**

Number of Storm Events

Even if the annual precipitation depth in a given year is roughly average, the number of storm events may not be average, as the individual events might tend to be either small or large. Having few very large events or many very small events is likely to skew pollutant load calculations and CSO volumes and frequencies and affect the evaluation of alternatives. Therefore, the number of events was determined for each of the 6 years and compared against the average value. In the 22-year record, the values for this statistic ranged from 92 to 139 events, with an average of 108. Table B-4 shows the values for the 6 years. Five of the 6 years had values close to the average, while 1950 had the highest number of storm events in the 22-year record at 139.

TABLE B-4
Number of Storm Events in New Haven for the 6 Years of Analysis

Year	Number of Storm Events
1950	139
1959	112
1960	106
1961	104
1967	114
1968	109
22-Yr Average	**108**

Maximum Event Volume

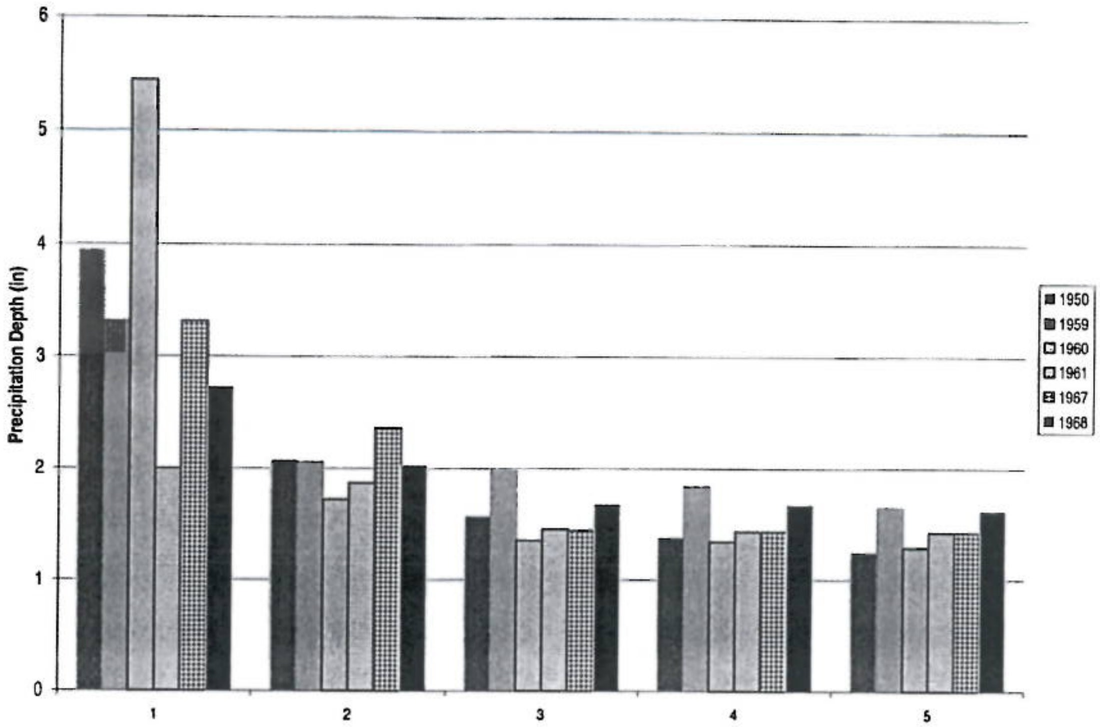
It is important when selecting a year that represents average conditions that there were no extreme events during the year. The maximum event volume in each of the 6 years was determined and compared to the average over the 22-year record. Maximum event volumes for the record ranged from 1.50 to 5.55 inches, with an average of 3.22 inches. Table B-5 shows the statistics for the 6 years analyzed, along with the return period for each event.[1] It can be seen that 1960 and 1961 had large and small maximum events, respectively, when compared to the average. The five largest event volumes in each year are depicted in Figure B-3.

TABLE B-5
Maximum Event Volumes in the 6 Years of Analysis in New Haven

Year	Maximum Event Volume (in)	Return Period of Maximum Event (yr)
1950	3.95	3.14
1959	3.32	2.44
1960	5.46	7.33
1961	2.00	0.47
1967	3.32	2.20
1968	2.73	1.16
22-Year Average	**3.22**	**2.06**

[1]The return period provides a measure of the size of a storm relative to other storms in the area. The return period is the number of years, on average, that would occur between storm events that are of a specified level. For example, a 10-year storm is of a magnitude that would occur, on average, once in 10 years.

FIGURE B-3
Five largest events (by volume) that occurred in each of the 6 years of analysis



Maximum Event Intensity

The last statistic that was analyzed was the maximum event intensity that occurred during each year. The maximum intensities ranged from 0.44 to 1.50 in/hr with an average of 0.96 in/hr. Figure B-4 shows the five largest event intensities for each of the 6 years. The maximum event intensities for the six years show much greater variation than the second through fifth greatest event intensities in each year.

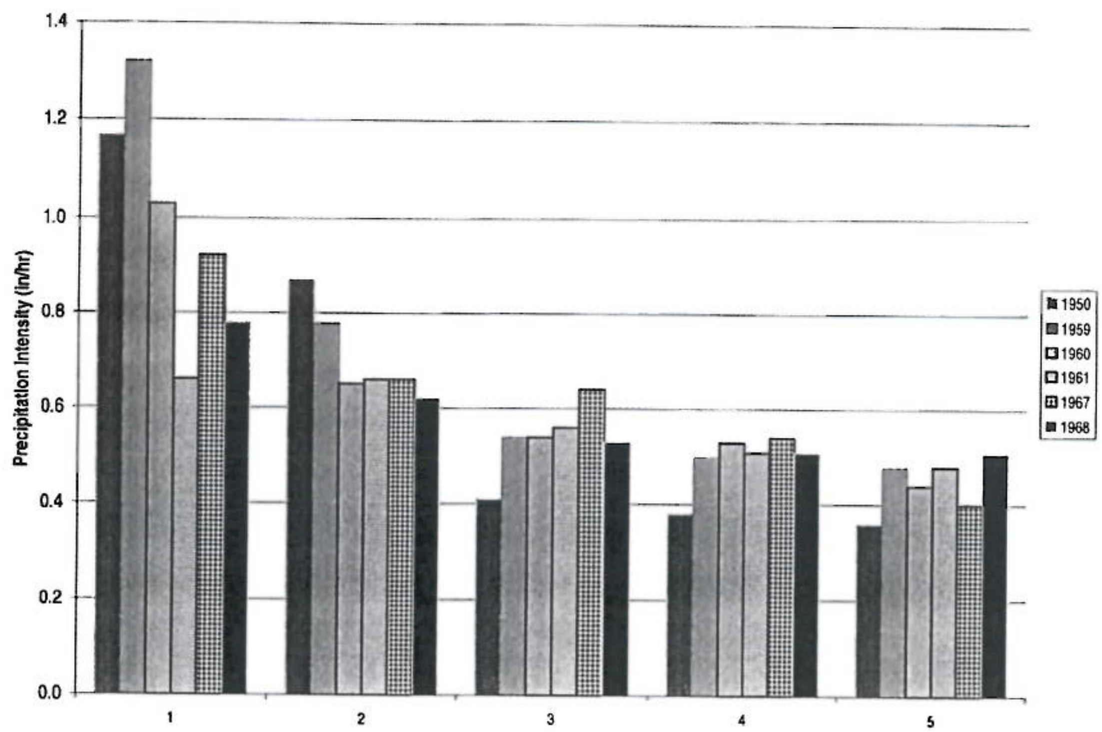
The Average Year: 1967

Table B-6 shows the 6 years ranked by each of the five criteria. Once all the statistics were calculated, 1967 was chosen as the year that best represents average conditions of the existing data set. Table B-7 summarizes why the other years were not selected.

TABLE B-6
Ranking of the 6 Years (+ good, o average, — bad)

Year	Annual Volume	Monthly Volumes	# of Events	Max. Event Volume	Max. Event Intensity	Total Rating
1950	+	+	—	o	o	+1
1959	+	—	o	+	—	0
1960	+	o	o	—	+	+1
1961	+	+	o	—	—	0
1967	+	+	o	+	+	+4
1968	+	—	o	o	o	0

FIGURE B-4
Five Largest Events (by Intensity) for Each of the 6 Years of Analysis



Drought

Although the foregoing analysis shows the year 1967 to be representative of average conditions in the 22-year period examined, concern was raised over the potential impacts from the drought in the 1960s on the choice of an average year. A similar analysis was performed for the Hartford data set, which spans 40 years (also including the drought, but the record is nearly twice as long as the New Haven data set). The year 1967 was also chosen as representative in the Hartford analysis.

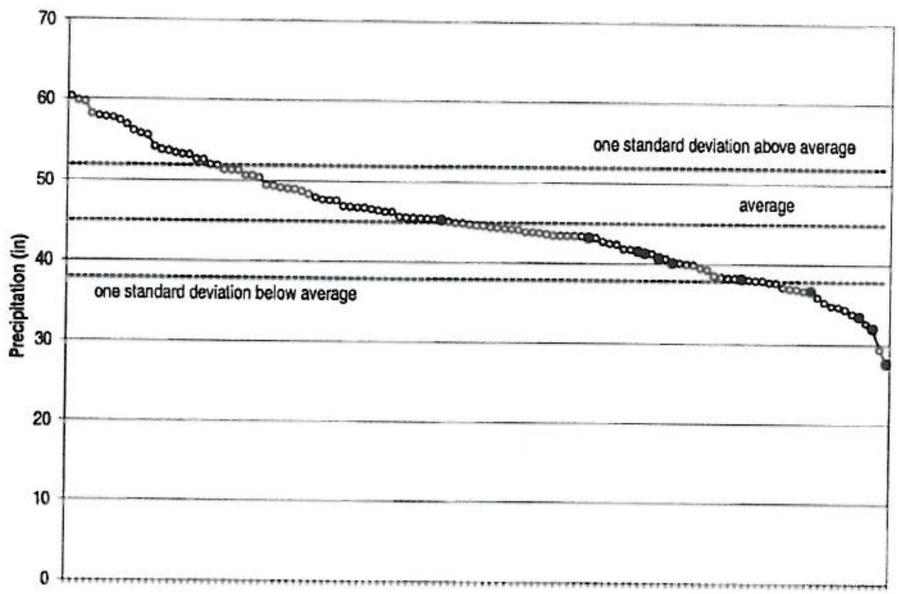
To help further examine the potential effects of the drought during the 1960s on the data sets, a long-term monthly data set from Bridgeport, a coastal city in Connecticut, was acquired. It included data from 1804 to 1983, although 1821 to 1872 and 1971 to 1980 data were missing (therefore, there were a total of 118 years in the data set). Figure B-5 shows the annual

TABLE B-7
Non-Average Conditions Causing the Years To Not Be Selected

Year	Non-Average Condition(s)
1950	Highest number of storm events in 22-year period
1959	Wet June and October, dry May and September, large maximum event intensity
1960	Large maximum event volume
1961	Small maximum event volume and intensity
1968	Wet June, November, and December, dry April and July

precipitation in each of these years graphed in descending order. The black dots represent precipitation for the years 1959 to 1969, when the drought occurred. It can be seen that almost all of the years fell below the long-term average, and 4 of the years had precipitation depths lower than one standard deviation below the average depth.

FIGURE B-5
Annual Precipitation in Bridgeport from 1804 to 1820, 1873 to 1970, and 1981 to 1983, with 1959-1969 highlighted



The average precipitation depths calculated from data sets from New Haven, Hartford, Bridgeport, and Providence and the depths for 1967 are shown in Table B-8. All data were recorded at airports in the cities. Note that all of these data sets encompassed the drought period, but longer data sets are less susceptible to its impacts. Though it is difficult to determine the exact cause of New Haven's lower average, it seems that the drought did impact the average in the short data set.

TABLE B-8
Long-Term Averages of Annual Precipitation Depth and Depth in 1967 in Several Cities

City	Years of Data Set	Average Annual Depth (in)	Depth in 1967 (in)
New Haven	1948–1969	41.27	40.63
Hartford	1954–1994	44.61	45.05
Bridgeport	1804–1820, 1873–1970, 1981–1983	44.96	40.69
Providence	1948–1994	45.10	46.54

Spatial Variation in Rainfall Intensity

The possibility of using Hartford rainfall data instead of New Haven data was considered. However, there was some concern raised about the variation in rainfall intensity between Hartford and New Haven. To address this issue, intensity-duration-frequency (IDF) curves for each city were examined. From the standard set of IDF curves (Technical Paper No. 25,

FIGURE B-6
Points from IDF Curves Comparing New Haven and Hartford Data (with emphasis on Short Duration Events)

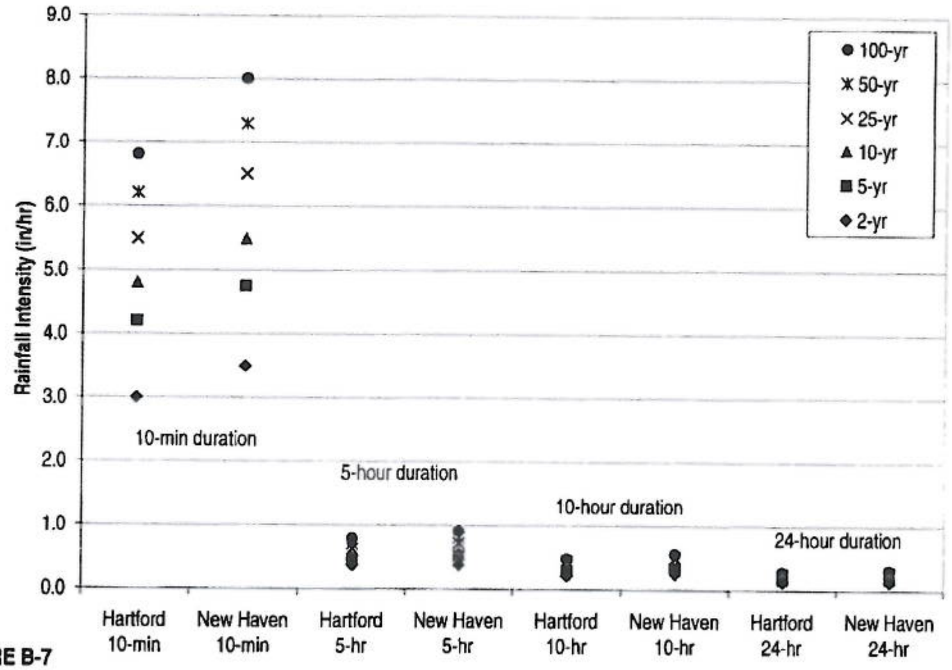
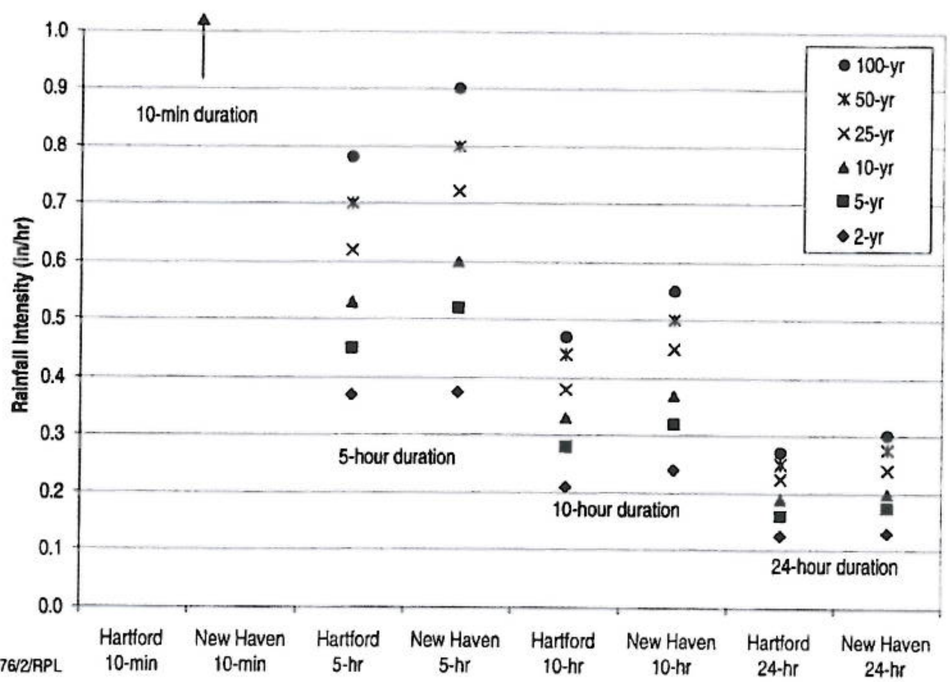


FIGURE B-7
Points from IDF Curves Comparing New Haven and Hartford Data (with Emphasis on Longer Duration Events)



U.S. Dept of Commerce 1955), the intensities associated with 6 different return periods were obtained for 4 different storm durations. Figures B-6 and B-7 show the sets of points graphed for both New Haven and Hartford. In all cases, the New Haven values are slightly more intense, ranging from 1 percent to 18 percent higher than the Hartford intensities. Because of the differences shown in Figures B-6 and B-7, it was decided not to use Hartford rainfall data.

Global Warming

A concern was raised regarding the use of a year that occurred more than 30 years ago that would not reflect any recent impacts from global warming. An annual data set from the Regional Water Authority's Lake Whitney Gauge was acquired for the years 1912 to 1997. Figure B-8 shows the annual precipitation values along with a linear trend line that indicates there has been no change in the trend in 85 years. Therefore, it appears that global warming has not shown any impact so far, and the use of 1967 rainfall data as representative is acceptable from this vantage point.

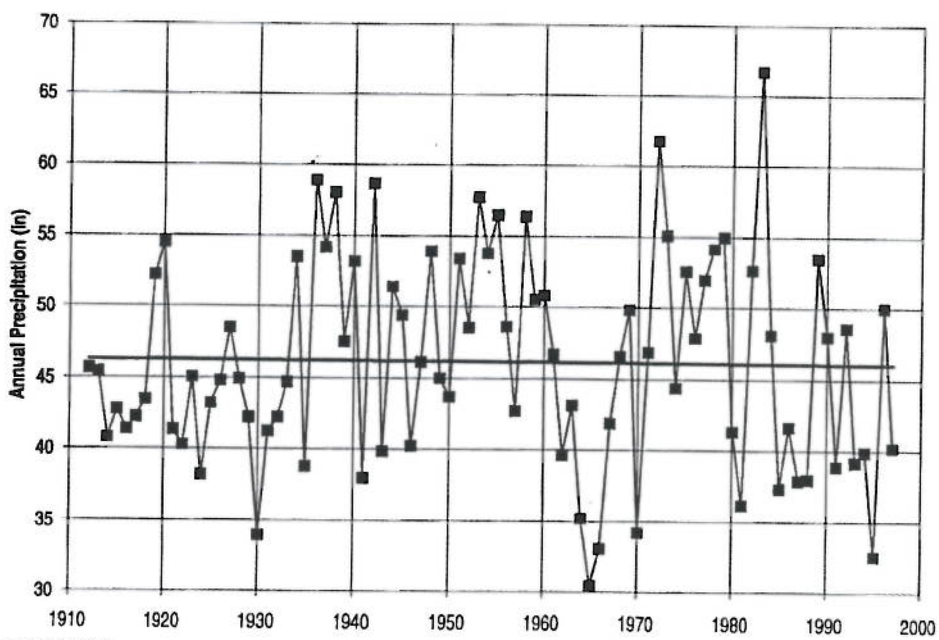
Summary

The year 1967 was chosen to represent average annual conditions for the purpose of the annual simulation in the project. Rainfall data from New Haven's Tweed Airport was used.

Tides

Tidal elevations for the year 1967 were not available for the New Haven Harbor. Data were obtained instead from a water level gauge at New London, CT (NOAA, 1999) and adjusted for the elevation and temporal offsets as found in the *Eldridge Tide and Pilot Book* (White and White, 1998).

FIGURE B-8
Annual Precipitation Depths at Lake Whitney Showing No Trends Over Time



APPENDIX C

East Shore WPAF Water Quality Data

This appendix includes a process flow diagram for the WPAF during wet and dry weather and several data charts that provide supplemental information to the WPAF description in the report.

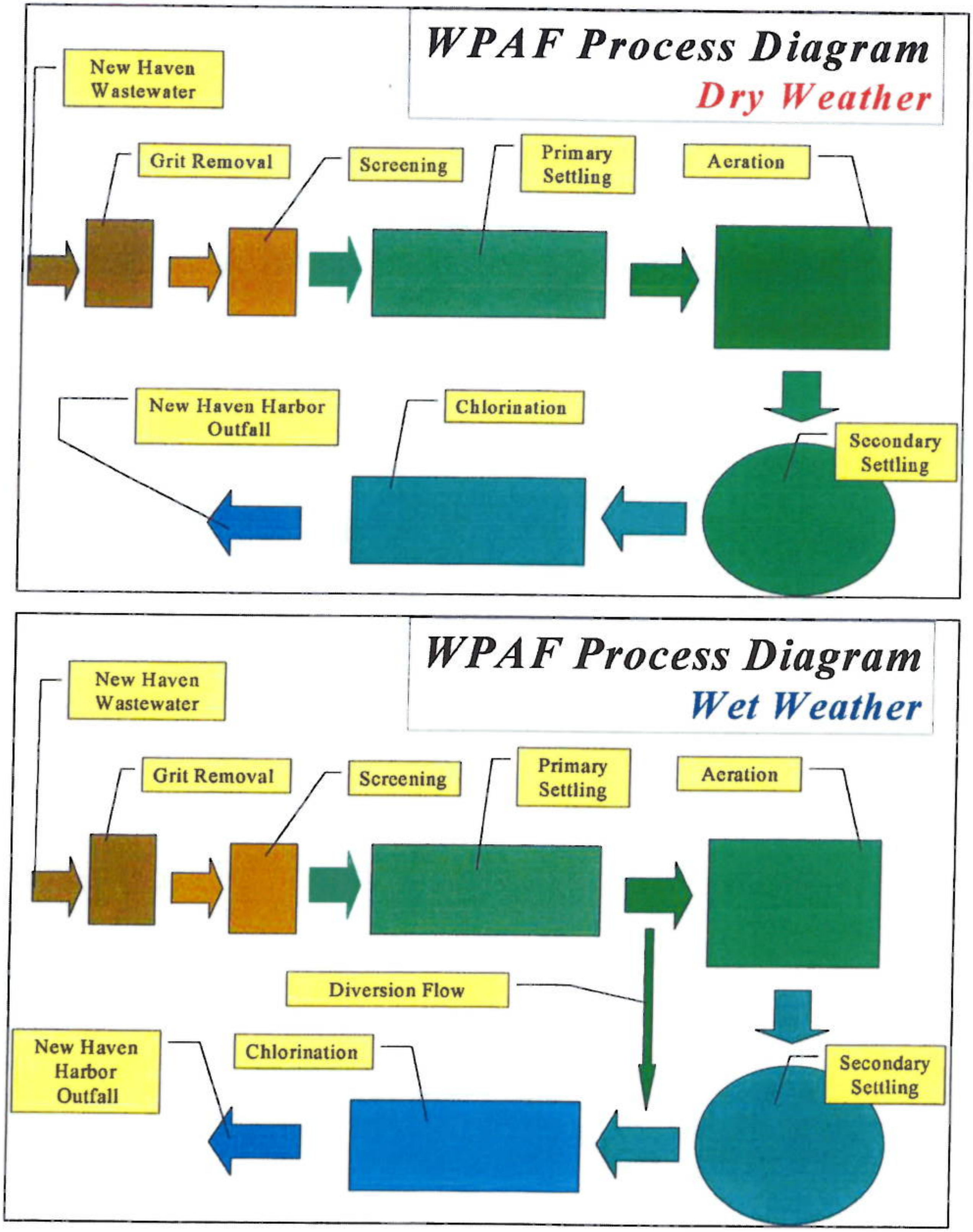


Figure C-1. Process Diagram of the East Shore WPAF During Dry and Wet Weather

Figure C-2
Total Daily Flow

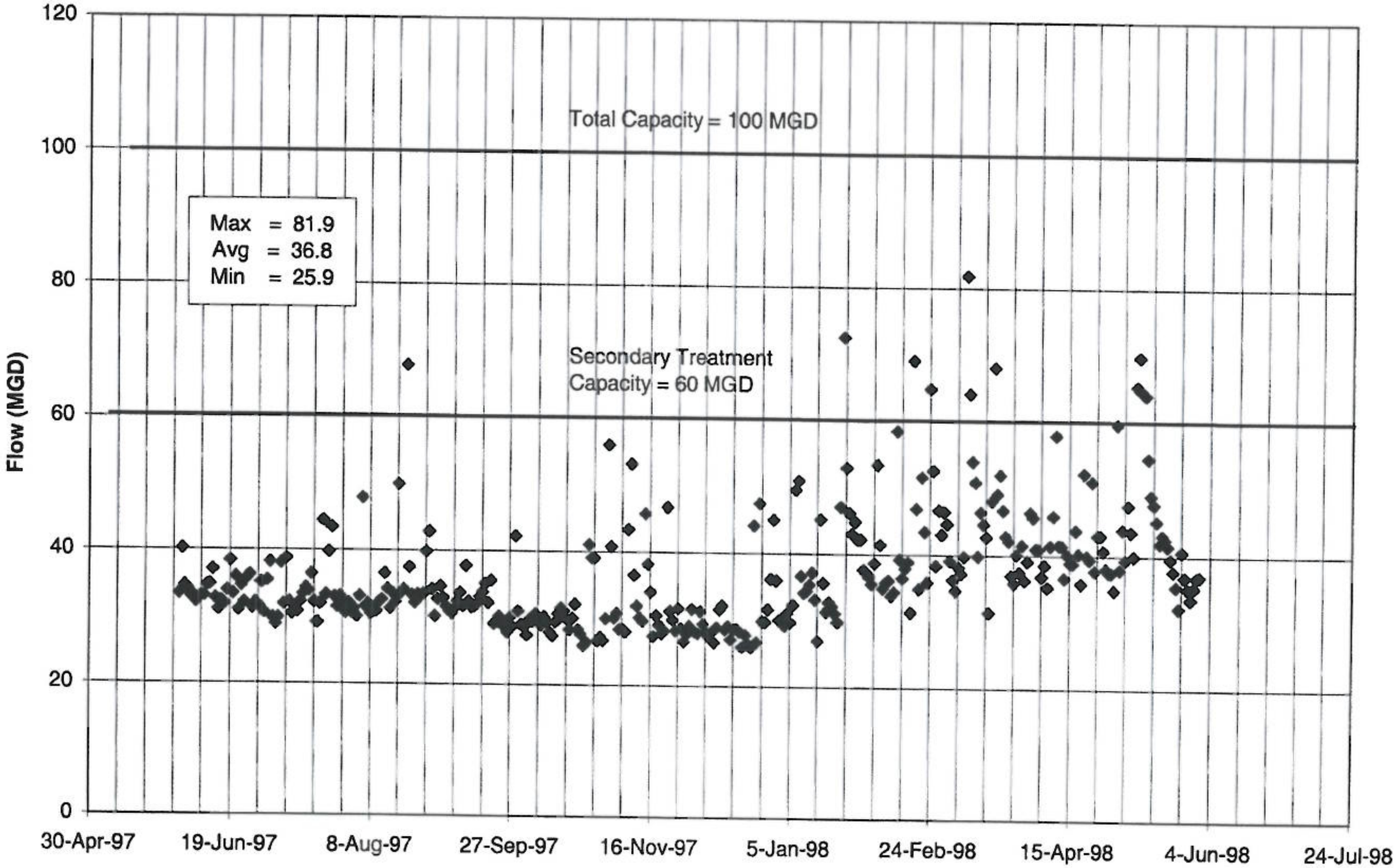


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Figure C-3
Diversion Volume

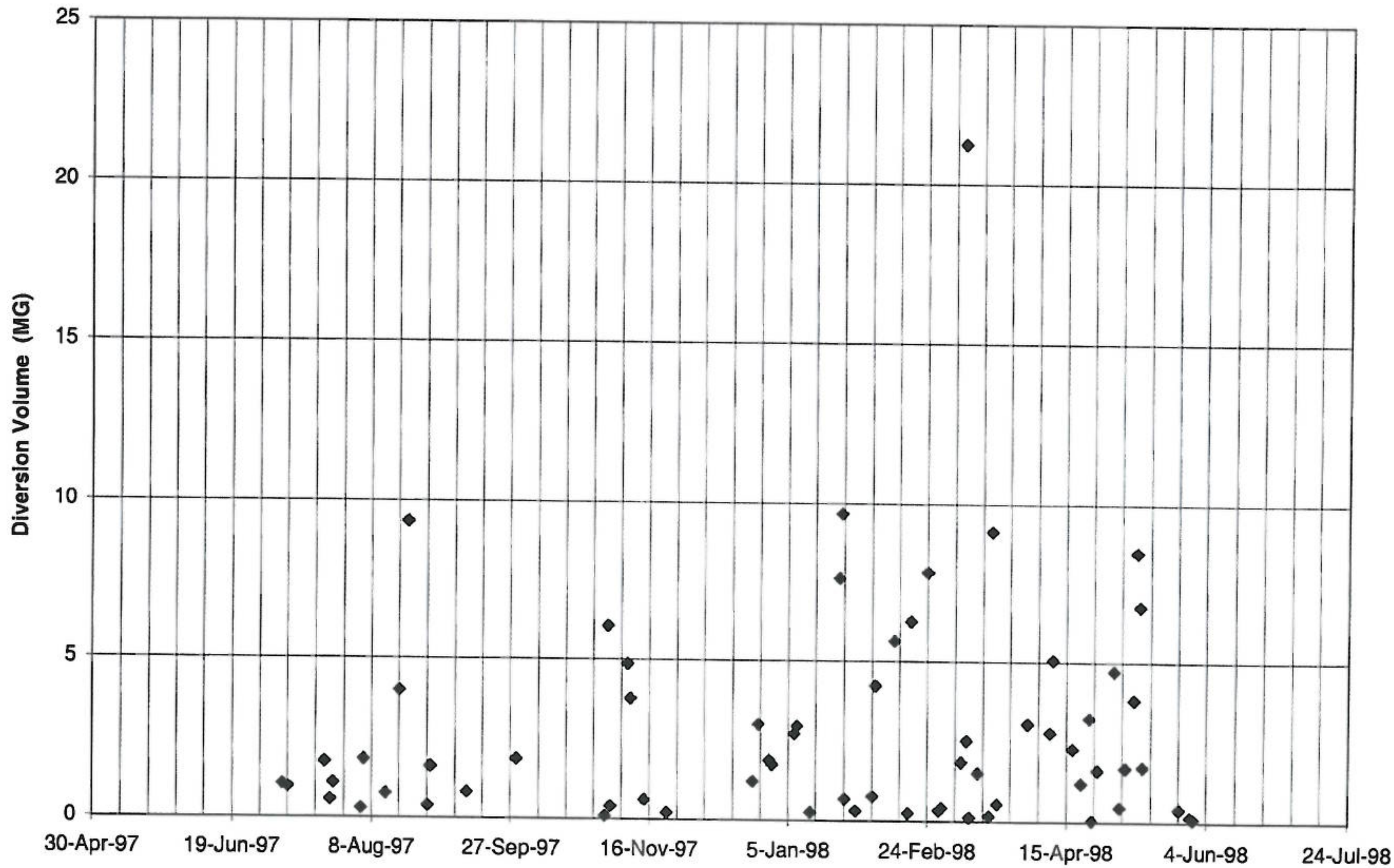

Figure C-4
Total Daily Diversion Flow vs. Rainfall from January to June

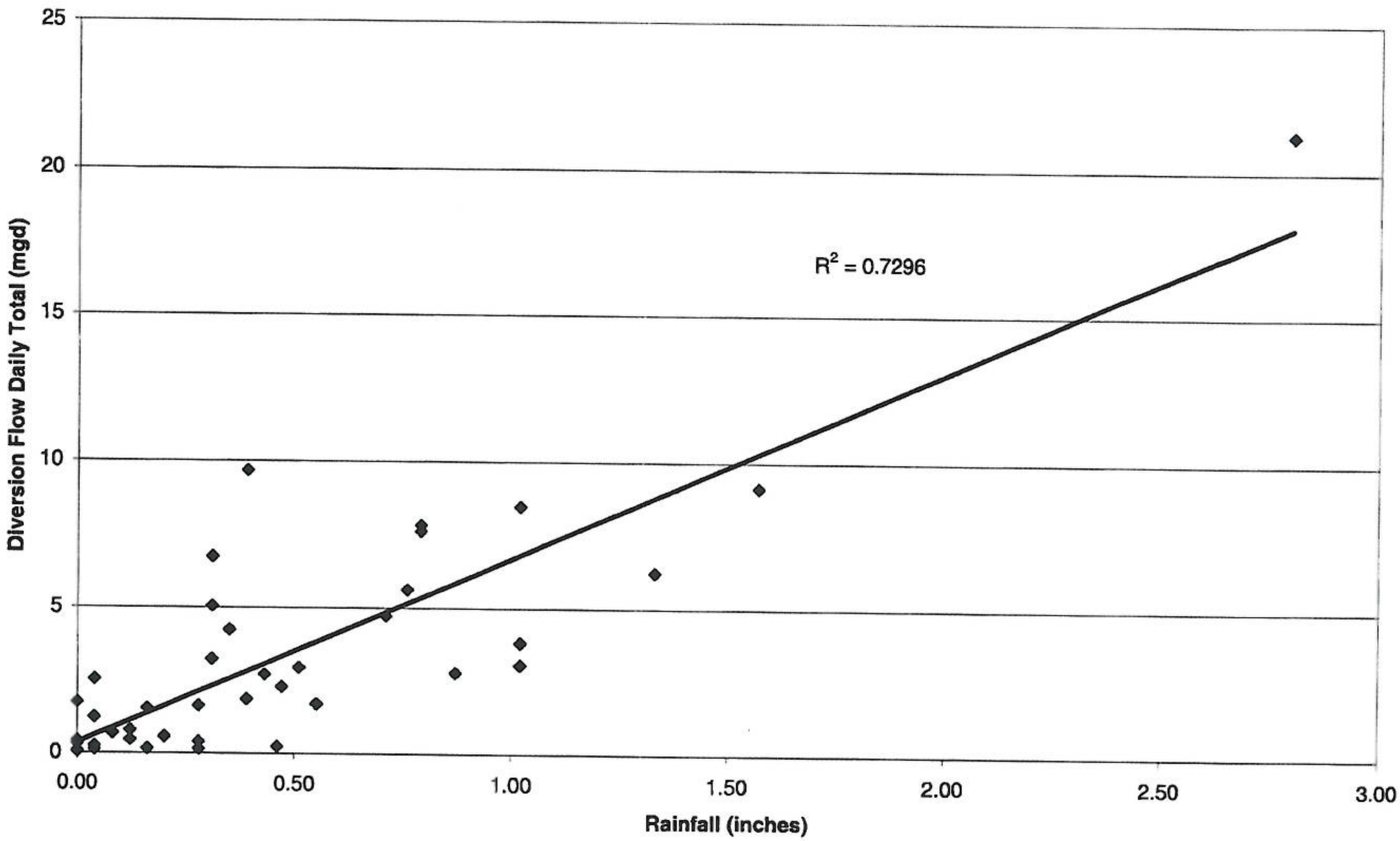

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Figure C-5

Total Daily Diversion Flow vs. Rainfall from July to December

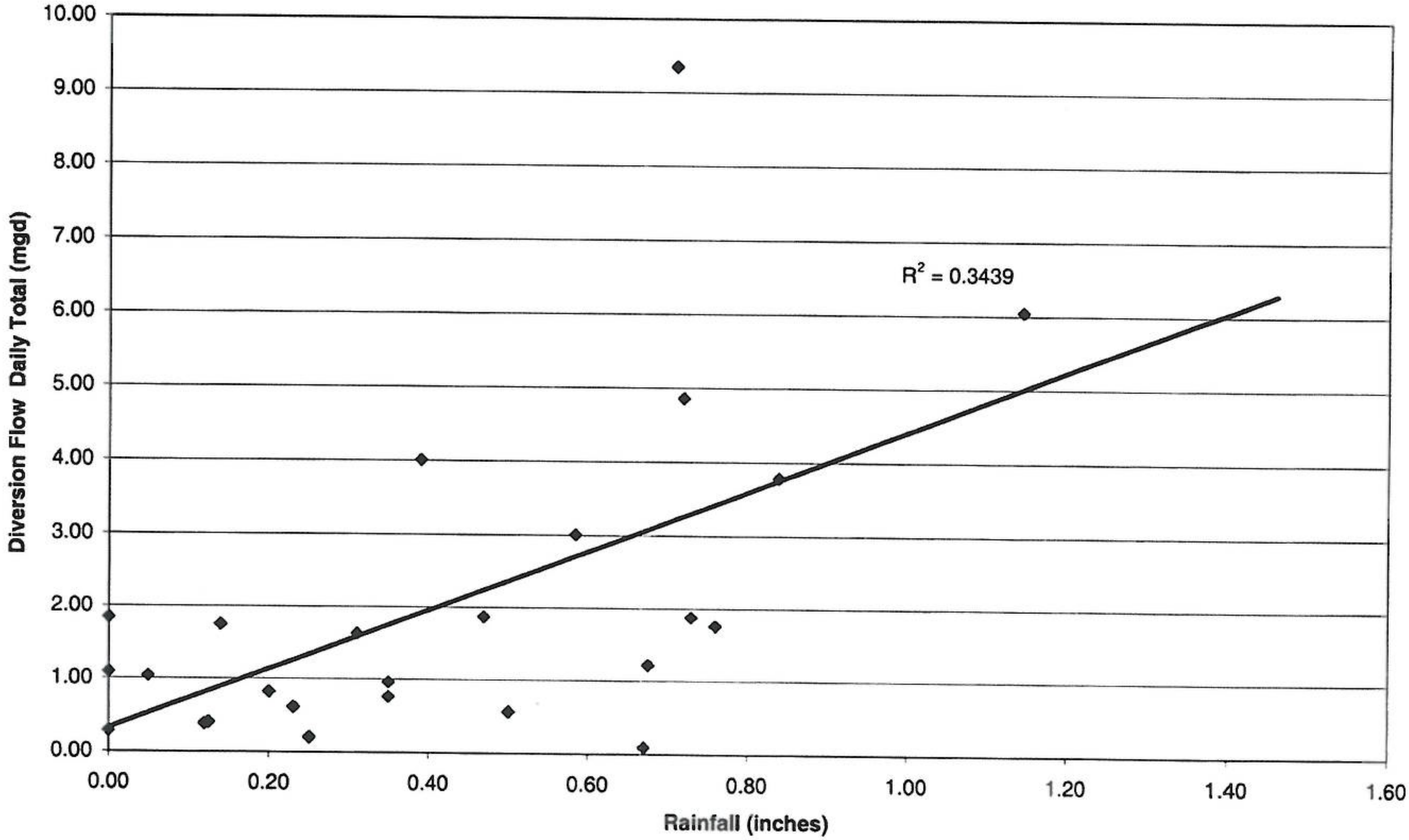

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Figure C-6
Effluent TSS

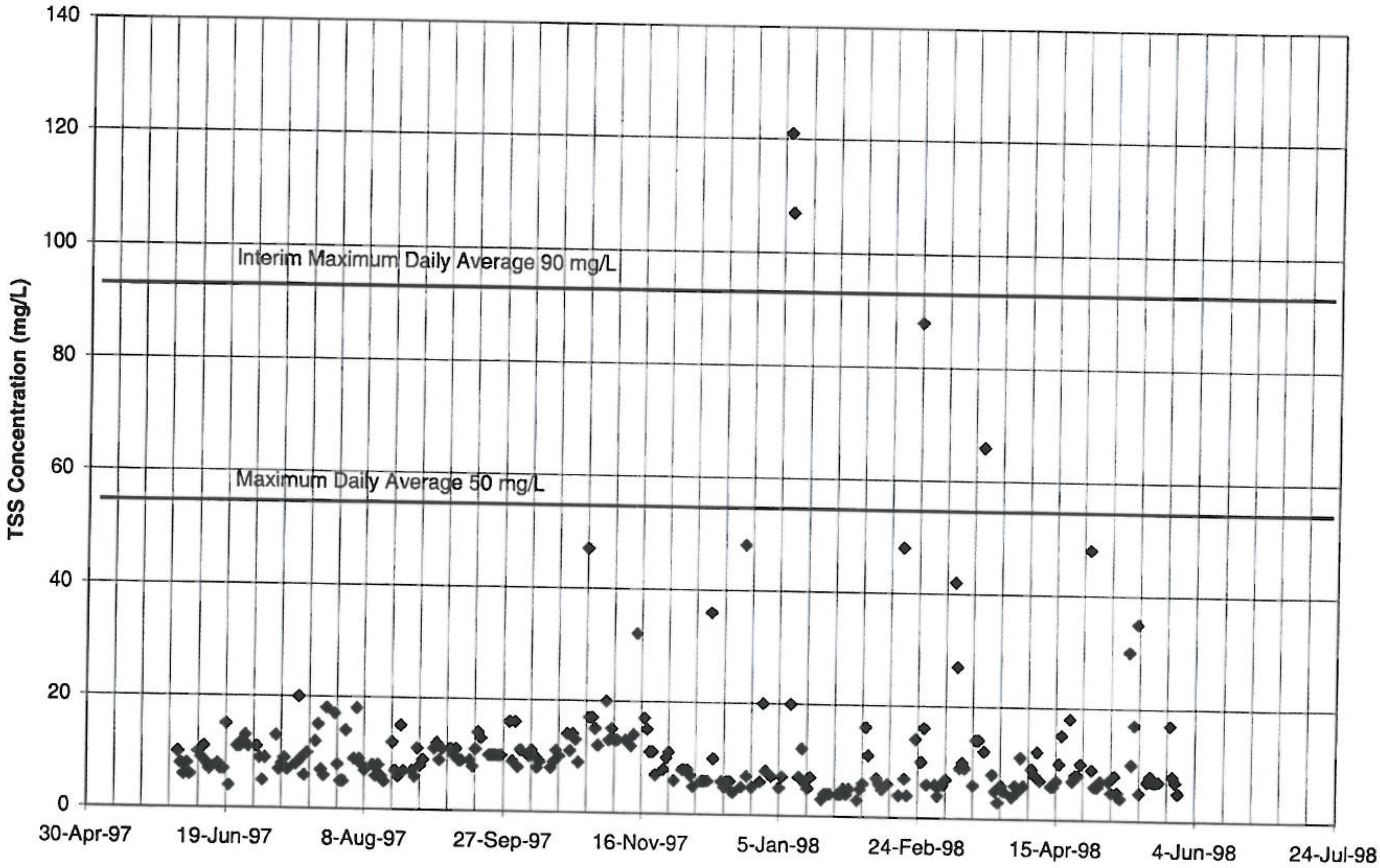

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Figure C-7

Diversion Flow vs. TSS Concentration

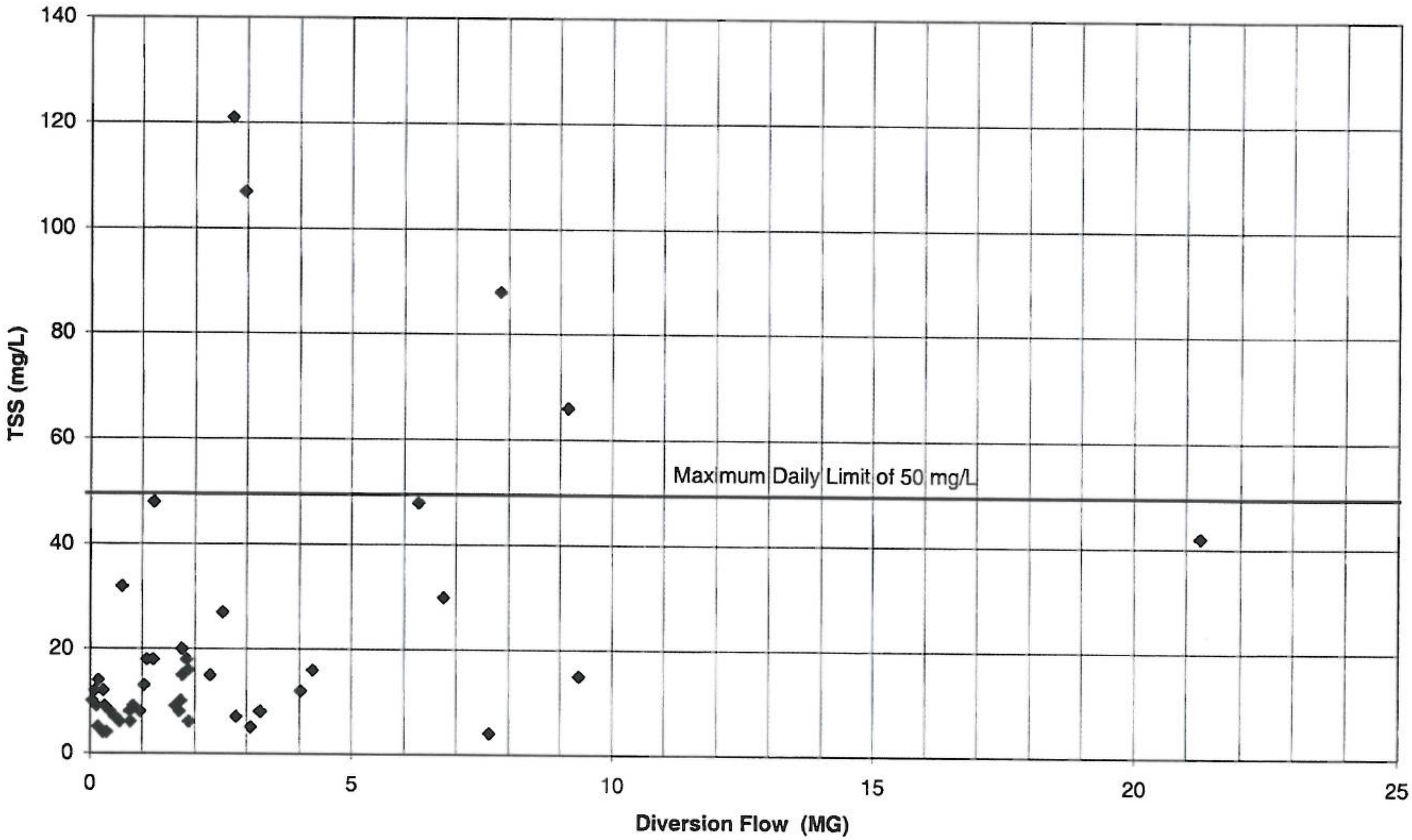

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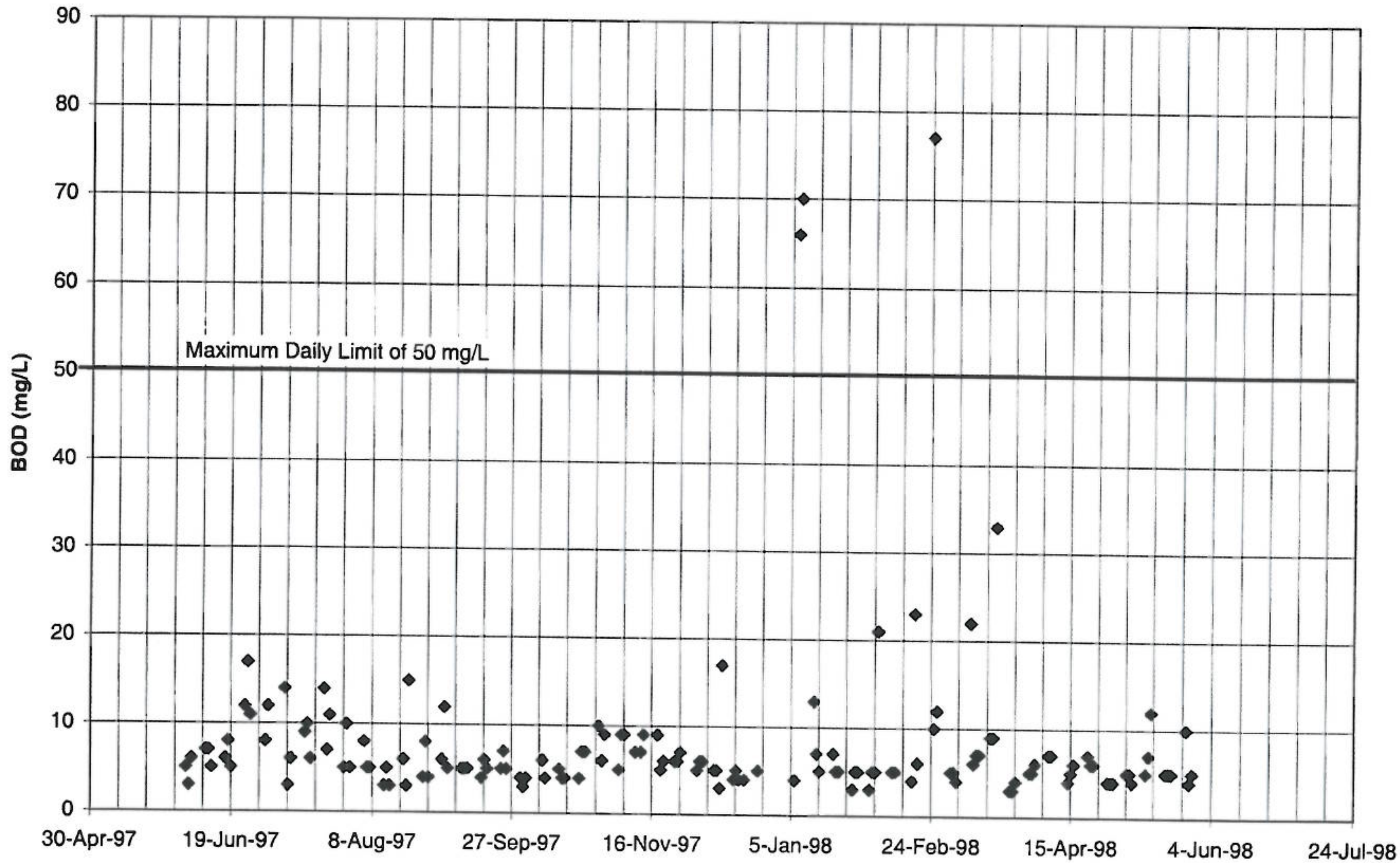
Figure C-8
Effluent BOD



GNH0006-155

Figure C-9
Diversion vs. BOD

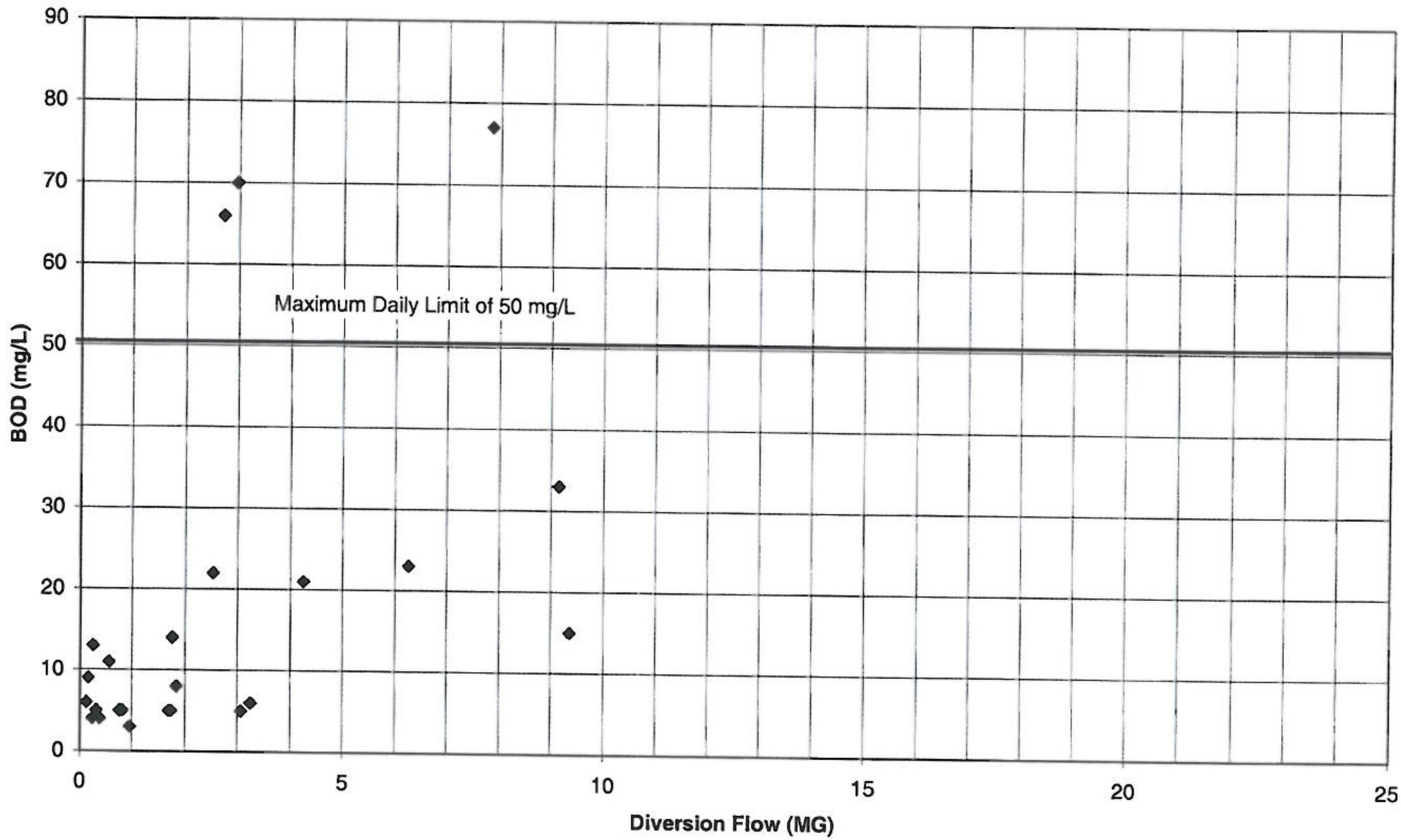


Figure C-10
Effluent Fecal Coliform

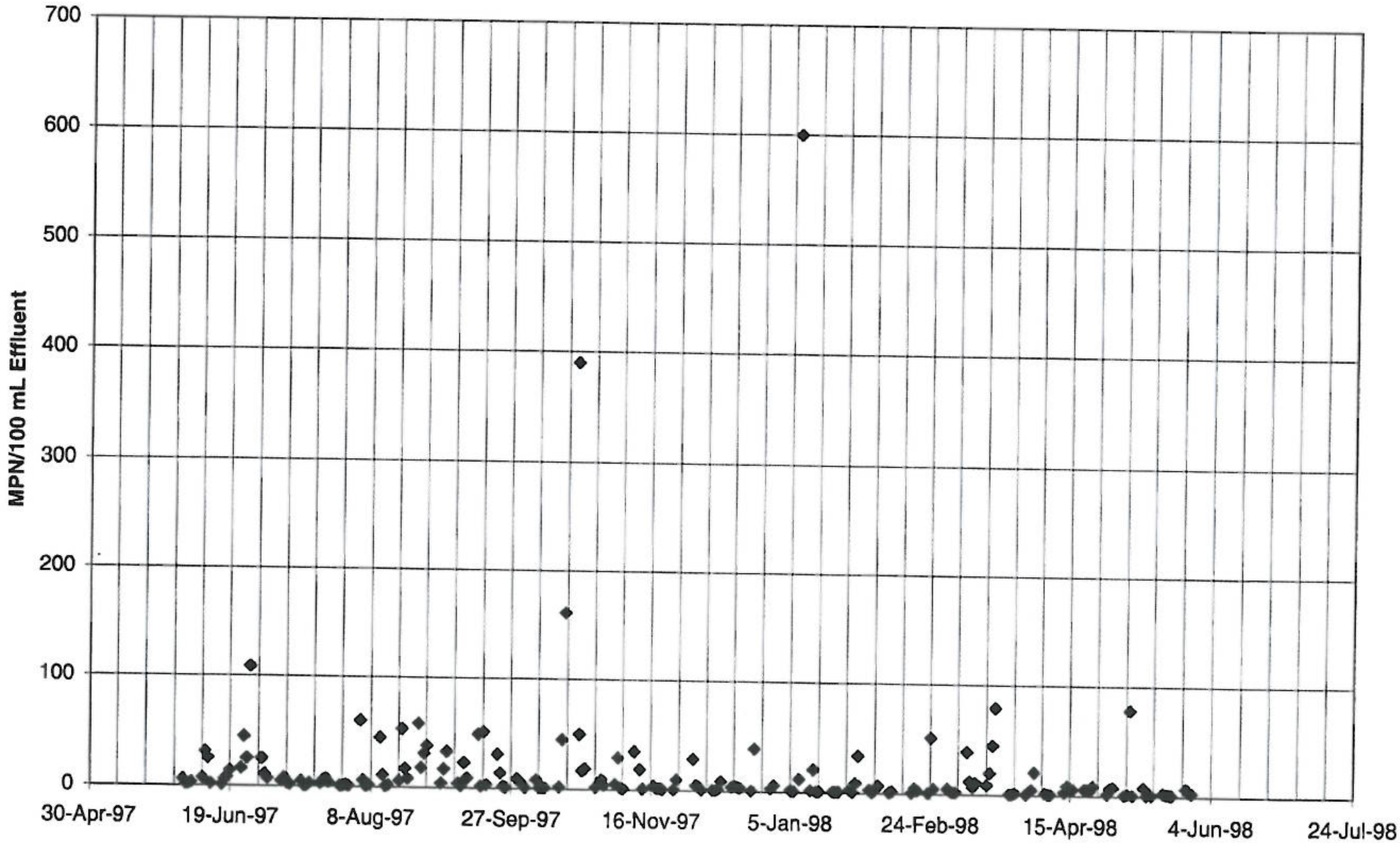


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Figure C-11
Fecal Coliform 7-Day Geometric Mean

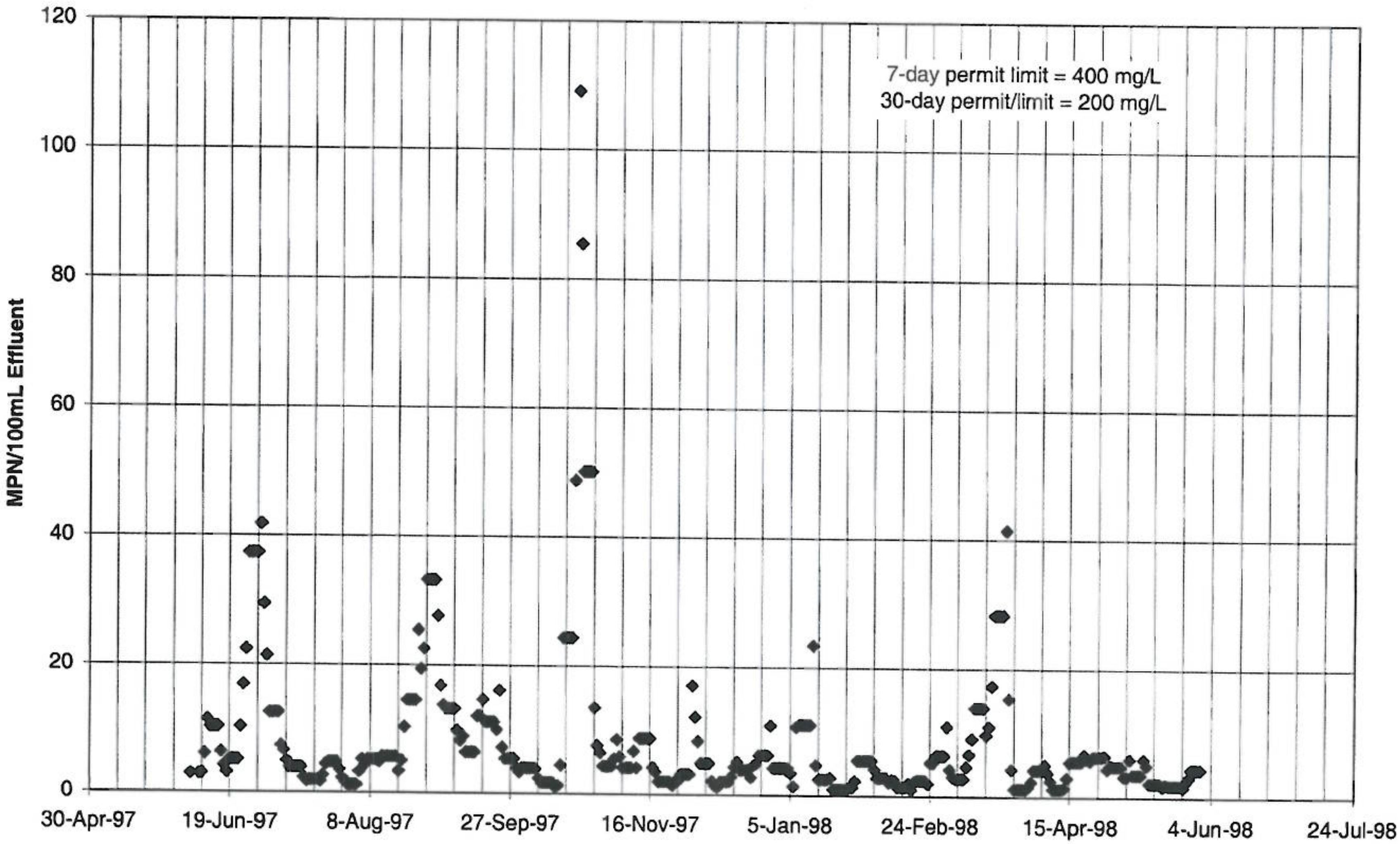

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Figure C-12
Total Nitrogen

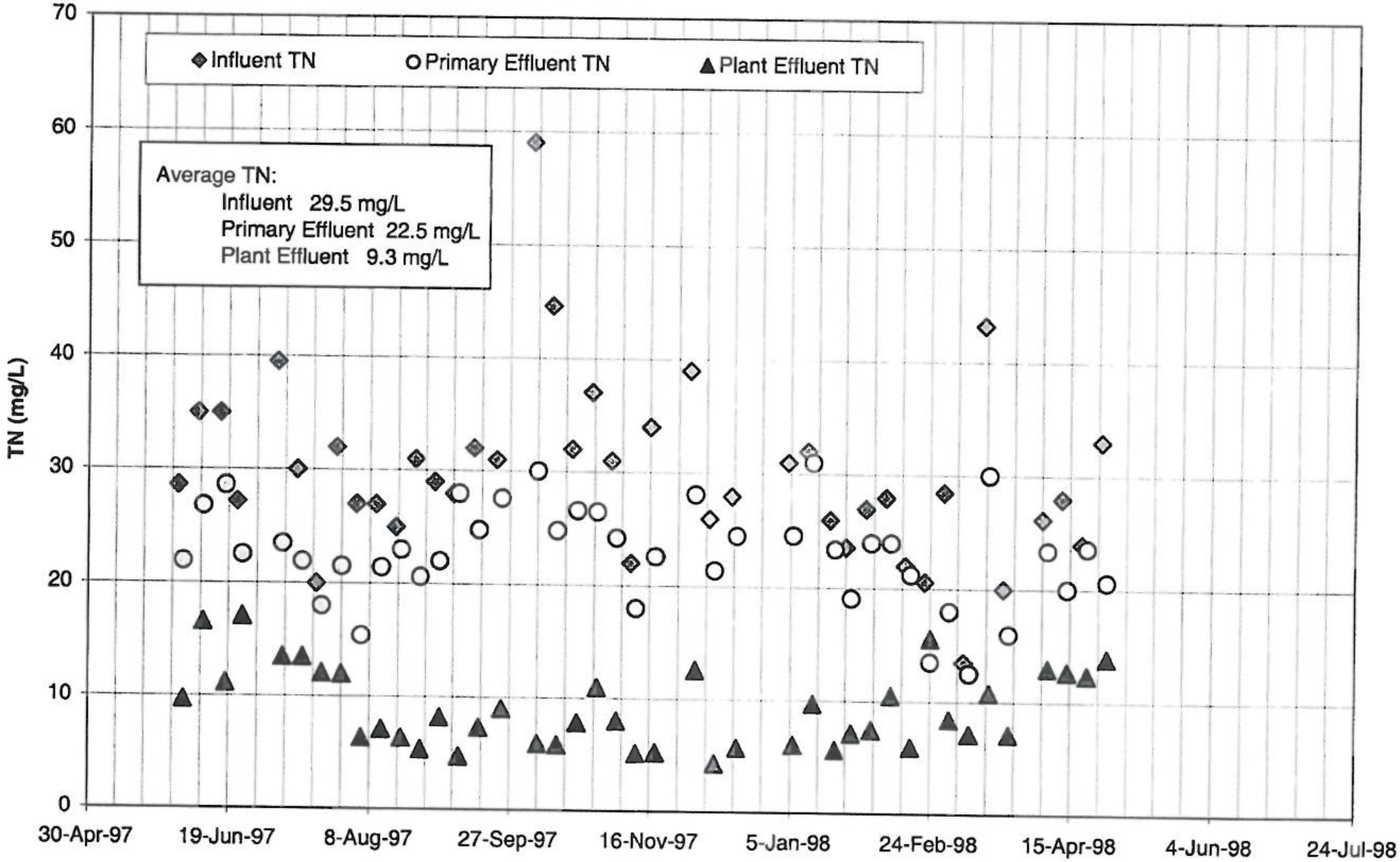

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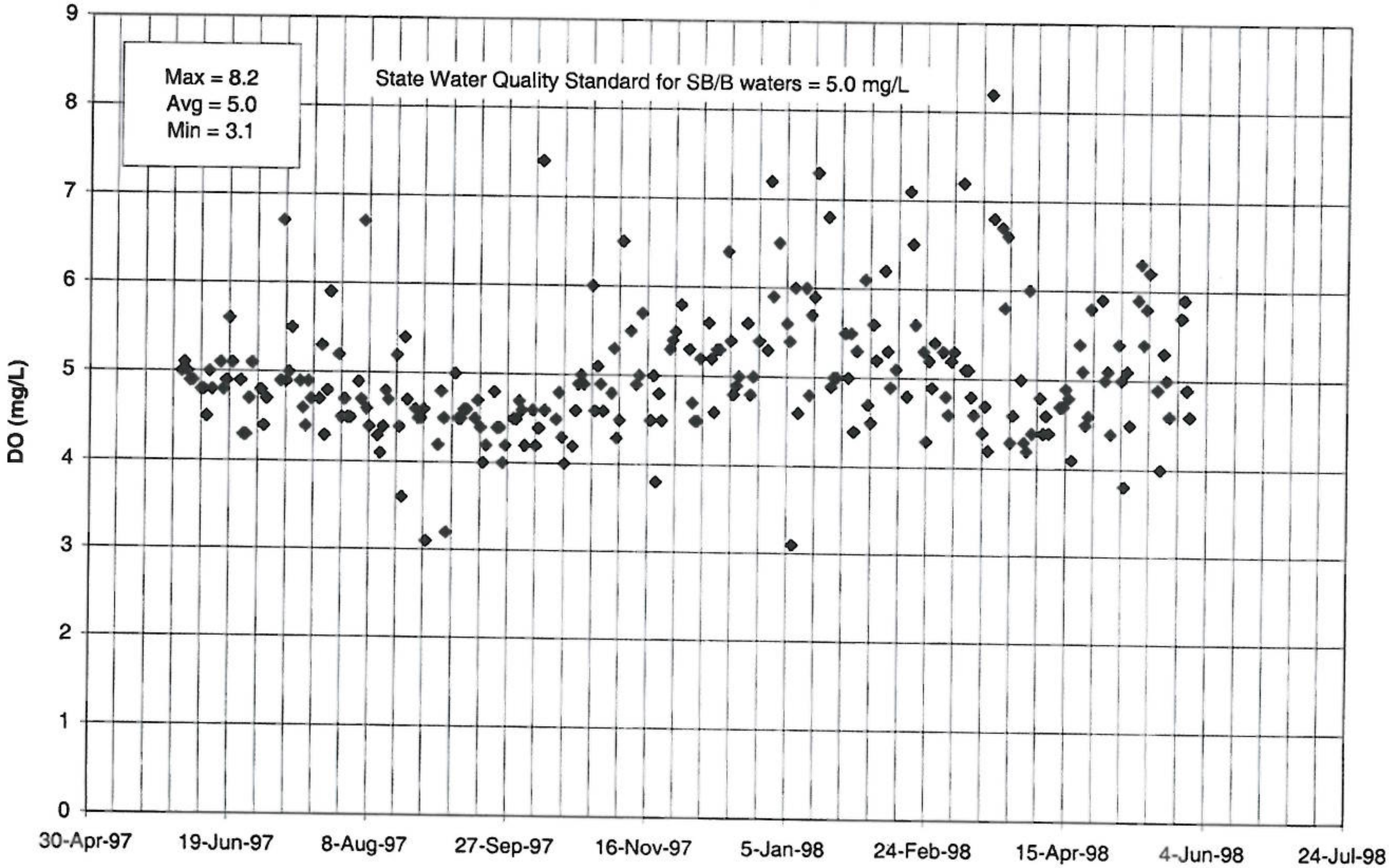
Figure C-13
Effluent DO



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